RESEARCH REPORT

THE APPLICATION OF STRUCTURAL STEEL TO SINGLE-FAMILY RESIDENTIAL CONSTRUCTION

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THE APPLICATION OF STRUCTURAL STEEL TO SINGLE-FAMILY RESIDENTIAL CONSTRUCTION

May 1999

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The application of structural steel to single-family residential construction

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Abstract

This study is an investigation of the use of structural steel in single-family residential construction, and an analysis of its applicability to Canada, taking into account technical requirements, cost-effectiveness, and sustainability.

With the rise of housing costs, global competition, and increasing environmental concerns, new systems and innovative uses of material are required to supplement the existing construction methods. Numerous studies have demonstrated the potential of steel for building and its advantage in terms of price, performance, and physical properties. Residential projects in steel are usually built with lightweight metal framing systems. Structural steel is seldom used, although it offers additional advantages in terms of performance, economy, flexibility, and speed of construction, as well as a wide availability of skills, trades, and experience from the commercial and industrial building sector.

The purpose of the study is to provide to decision-makers in the building industry a clear view of the possibilities offered by the application of structural steel to housing.

The 200-pages report addresses the following topics:

- steel and metal building systems in the context of housing
- existing steel houses worldwide and in Canada
- source of information for steel technology
- compliance with building codes
- Canadian steel suppliers and trades
- prototype design of a steel house
- steel house and sustainability.

Purpose

This study is an investigation of the use of structural steel in single-family residential construction, and an analysis of its applicability to Canada, taking into account technical requirements, cost-effectiveness, and sustainability.

With the rise of housing costs and increased global competition, new systems and innovative uses of material are required to supplement the existing construction methods. Numerous studies have demonstrated the potential of steel for building and its advantage in terms of price, performance, and physical properties. Residential projects in steel are usually built with lightweight metal framing systems. Structural steel is seldom used, although it offers additional advantages in terms of performance, economy, flexibility, and speed of construction, as well as a wide availability of skills, trades, and experience from the commercial and industrial building sector.

The purpose of the study is to provide to decision-makers in the building industry a clear view of the possibilities offered by the application of structural steel to housing.

Executive Summary

Structural steel is seldom used in single-family residential construction although it offers many technical, economical, and environmental benefits. Building a "*steel house*" using structural steel is a method radically different from the conventional wood, -or steel stud- framing system. It uses industrial/commercial techniques and components such as:

- an independent column and beam structural steel system carrying all the loads
- non-bearing insulated panels for the walls
- concrete and steel decks for the floors
- prefabrication and building system technology

Structural steel in residential construction is very efficient and cost-effective, but its wide application to the housing market requires a major mind shift of the part of the building professional as well as overcoming public misconception about steel. However, recent trends in the construction industry are showing positive signs of changes. These signs are:

(1) the *new steel* or the revitalization of a leaner, cleaner, and more efficient North American steel industry,

(2) the *rise of the building system* or the increasing market share of metal building system in the industrial/commercial building market, and

(3) the *mobile home boom* or the increasing number of people buying pre-manufactured homes.

The new challenge

These three trends indicate a shift in construction technology toward building systems, modularity, and pre-manufacturing, using sustainable, recyclable steel. The application of these new concepts to residential construction involves:

- the use of "industrial" materials rationally chosen for their physical and environmental values, ease of construction, and cost, rather than for their traditional meaning,
- a functional and flexible design that allows for future changes in space and usage.
- the prefabrication and standardization of building elements that reduce cost and improve quality.
- a fast construction method that reduces financial charges and permits fast occupancy

Structural steel offers many advantages such as: strength, stability, durability, recyclability, lightness, spatial flexibility, adaptability, productivity, and fast assembly. Yet, the application of steel system building to residential construction meets many obstacles:

- Steel is not well accepted by residential contractors.
- An industrial metal building is not a house, considering the difference in need and functions.
- A manufactured home may have restrictions in terms of size and zoning and may still be considered a low-end product.
- Traditions and socio-cultural functions have a very strong influence on the market.

The challenge is therefore to apply the rational and cost-effective techniques of the steel building system to residential construction while overcoming the barriers related to tradition and to existing standards.

Rationale

Steel is an economically and ecologically-sound response to housing because it fosters the conservation of resources throughout the life-cycle of the building. An in-depth analysis of 158 steel houses built during the 20th century provides clear evidences that steel can deliver superior performances in housing. The use of steel permits to reduce the amount of material, space, energy, and time spent in a building and therefore, reduces its costs and environmental impacts. While the users are usually extremely satisfied with their steel houses, the study shows that a wider acceptance of steel houses would require a new approach by building professionals. A steel houses requires planning and system building methods that lead logically to a *Design-Build-Finance* approach where a single company designs, manufactures, sells, finances, installs, and guarantees the building.

Applicability to Canada

A steel house in Surrey, B.C. demonstrated that structural steel can be successfully applied in Canada. The cost was similar to traditional wood frame construction, despite the experimental nature of the project. The construction went fast and employed mainly contractors from the industrial / commercial sector who had no previous experience in residential construction. The house provides a great living space, is energy-efficient, requires little maintenance, and has superior value.

A steel house must conform to the structural design clauses of the Canadian National Building Code (NBC) that requires engineering supervision of the design and construction of the steel structure and may create additional costs. A better integration of engineering in the whole design and construction process can however greatly reduce or even eliminate these additional costs. Other requirements of the NBC related to the use of steel are straightforward and compliance can be achieved at low or no extra cost.

There are many agencies and organizations in the world dealing with steel that form an excellent source of information for techniques related to steel, steel construction, steel building systems, and components. In Canada, the application of structural steel to residential construction may rely on the wide availability of local skills, trades and experience. The Canadian steel industry is active at every phase of the steel production and fabrication, and is present in every province of Canada. There are about 250 steel fabricators distributed in every region of Canada. Overall, they have the capability of fabricating and building steel houses without any significant technology change. Moreover, they often have the capability to provide full design-built services, including conceptual and detailed design, fabrication, and erection.

Building with steel requires the services of structural engineers, detailers, and in most cases, the input of architects. These professionals are widely available across Canada. Nowadays, consulting engineers often provide turn-key services including financing, design, and construction. This formula could be easily adapted to the supply of steel houses.

Steel house prototype

This report includes the design of an affordable steel house that could be used as a prototype to demonstrate the advantages of building with steel. It will cost less to build than a wood frame house of similar size and it will have lower operation and maintenance costs because the building is stronger, more flexible, more adaptable, more energy-efficient, and more durable.

The steel structure weights less than 5 tonnes and costs less than 15 percent of the total cost of the building. The site assembly of the main components can be done in less than 3 weeks, significantly reducing the cost of labour and financing and allowing building in remote sites or difficult climates.

Sustainability

One of the major challenge of the coming century is keep the economy within the capacity of the ecosystem to support it is. That is the concept of sustainability. Sustainability in construction require a new approach and new design criteria in addition to the usual economic or aesthetic considerations. The goal is to do more with less through resource conservation and dematerialization. Methods to reach this objective include:

- system integration, using fewer, better integrated components
- value optimization, replacing quality by quantity, and material by information
- life-cycle planning, using durable, reusable, recyclable materials
- environmental impacts minimization throughout the life cycle

The results of this study give strong indications that the use of steel in residential construction is a solution toward sustainability because it does more with less, reduces the consumption of resources and energy, and provides higher-value, more durable and flexible building system.

The wider application of steel to residential construction should promote the transition from economic growth to qualitative development, towards a sustainable housing industry.

Sommaire

Bien que l'acier de construction soit rarement employé pour la construction de maisons individuelles, il présente de nombreux avantages techniques, économiques et environnementaux. La construction d'une *«maison d'acier»* est une méthode radicalement différente de l'assemblage classique à ossature de bois ou d'acier. Elle fait appel à des techniques et des composants industriels/commerciaux tels que :

- un système autonome à poteaux et poutres en acier de construction portant toutes les charges
- des panneaux isolés non porteurs pour les murs
- des platelages de béton et d'acier pour les planchers
- préfabrication et techniques de construction par systèmes

La construction résidentielle en acier est très efficace et rentable, mais il faudrait un changement de paradigme chez les constructeurs et contrer les préjugés du public à l'égard de l'acier pour que son usage se répande sur le marché de la construction. Or, les tendances récentes dans l'industrie de la construction sont prometteuses, à savoir :

1. le *nouvel acier* ou la revitalisation d'une industrie devenue plus rationnelle, propre et efficace en Amérique du Nord,
2. la *popularité croissante du système de construction* ou la part de marché croissante des systèmes de construction métallique dans les secteurs de construction industriels et commerciaux,
3. l'*essor des maisons mobiles* ou le nombre croissant de personnes qui achètent des maisons préfabriquées.

Le nouveau défi

Ces trois tendances laissent entrevoir que les systèmes de construction, la modularité et la préfabrication utilisant de l'acier recyclable et durable l'emporteront sur les technologies de construction classiques. En construction résidentielle, ces nouveaux concepts impliquent :

- l'utilisation de matériaux «industriels» sélectionnés de manière rationnelle pour leur avantages physiques et environnementaux, la facilité de construction et leur coût, plutôt que pour les raisons habituelles,
- une conception fonctionnelle et souple permettant des adaptations d'espace et d'utilisation,

- des coûts réduits et une meilleure qualité grâce à la préfabrication et à la normalisation des éléments de construction,

- une méthode de construction rapide qui diminue les frais financiers et permet une occupation sans délai.

L'acier de construction a de nombreux avantages : solidité, stabilité, durabilité, recyclabilité, légèreté, flexibilité spatiale, adaptabilité, productivité et assemblage rapide. Pourtant, nombreux sont les écueils à son application en construction résidentielle.

- Les constructeurs d'habitations sont rébarbatifs en ce qui concerne l'acier.

- Un bâtiment industriel en métal n'est pas une habitation, les besoins et les fonctions étant différents.

- Une maison usinée peut faire l'objet de contraintes relatives aux dimensions et au zonage, et peut aussi toujours être perçue comme un produit bas de gamme.

- La tradition et les fonctions socio-culturelles influent beaucoup sur le marché.

Le défi consiste donc à appliquer les techniques rationnelles et rentables du système de construction en acier à la construction résidentielle, tout en surmontant les obstacles posés par la tradition et les normes courantes.

Raisonnement

L'acier est une option économique et écologique dans le domaine du logement parce qu'il implique la conservation des ressources naturelles tout au long du cycle de vie d'un bâtiment. Une analyse approfondie de 158 maisons à ossature d'acier construites au XXe siècle montre sans équivoque que l'acier peut donner une performance supérieure dans le secteur résidentiel. L'utilisation d'acier permet de réduire la quantité de matériaux, d'espace, d'énergie et de temps consacrés à la construction, donc réduit les coûts et les incidences environnementales. Même si les clients sont normalement très satisfaits de leur maison à ossature d'acier, l'étude révèle qu'il faudrait que les constructeurs adoptent une nouvelle approche pour faire accepter l'acier davantage. Une maison à ossature d'acier requiert une planification et des méthodes de construction basées sur une approche *Conception/Construction/Financement*, où une seule entreprise dessine, fabrique, vend, finance, installe et garantit le bâtiment.

Applicabilité au Canada

Une maison à ossature d'acier à Surrey (Colombie-Britannique) a permis de démontrer que l'acier de construction peut être utilisé avec succès au Canada. Son coût, malgré l'aspect expérimental du projet, a été à peu près le même que celui d'une maison à ossature de bois. Le construction a été rapide et a été exécutée par de nombreux entrepreneurs du secteur industriel/commercial qui n'avaient aucune expérience en construction résidentielle. La maison est très bien, efficace sur le plan énergétique, exige peu d'entretien et a une valeur supérieure.

Une maison à ossature d'acier doit être conforme aux dispositions de conception structurale du Code national du bâtiment du Canada (CNBC), prescrivant la supervision par un ingénieur de la conception et de la construction de l'ossature d'acier, ce qui peut en augmenter le prix. Toutefois, une meilleure intégration des services d'ingénierie dans tout le processus de conception et de construction pourrait presque éliminer ces frais supplémentaires. Les autres exigences du Code concernant l'utilisation d'acier ne présentent pas de complications et on peut donc s'y conformer à peu de frais.

Il existe dans le monde beaucoup d'organismes qui constituent une mine d'informations sur les techniques, la construction, les systèmes de construction et les composants d'acier. Au Canada, l'utilisation d'acier de construction dans le secteur résidentiel pourrait être fonction de la disponibilité d'un grand nombre de corps de métier et de leur expérience. L'industrie canadienne de l'acier intervient à tous les stades de la production et de la fabrication d'acier, et elle existe dans toutes les provinces canadiennes. On trouve environ 250 fabricants d'acier dans toutes les régions du Canada. Tous réunis, ils ont la capacité voulue pour fabriquer et construire des maisons à ossature d'acier sans réoutillage important. De surcroît, ils sont nombreux à pouvoir offrir des services complets de conception/construction, y compris concepts et dessins détaillés, fabrication et montage.

La construction en acier exige les services d'ingénieurs de structure, de dessinateurs-détaillants et, dans bien des cas, d'architectes. Ces professionnels ne manquent pas au Canada. De nos jours, les ingénieurs-conseils offrent fréquemment un service «clés en main» (financement, conception et construction). Cette formule pourrait aisément être adaptée aux maisons à ossature d'acier.

Prototype de maison à ossature d'acier

Le rapport comprend un modèle de maison à ossature d'acier à prix abordable qui pourrait servir de prototype pour montrer les avantages de la construction en acier. Elle coûterait moins cher qu'une maison de taille similaire à ossature de bois; les coûts de fonctionnement et d'entretien seraient inférieurs parce que le bâtiment est plus résistant, flexible, adaptable, éconergétique et durable. Les principales composantes peuvent être assemblées en moins de trois semaines, ce qui diminue appréciablement le coût de la main-d'oeuvre et du financement, et convient aux régions isolées ou aux climats rigoureux.

Durabilité

L'un des grands défis du siècle prochain sera de ne pas surtaxer notre écosystème par nos activités économiques. C'est le principe de la durabilité. La durabilité en construction exige une nouvelle approche et de nouveaux critères de conception, outre les considérations économiques et esthétiques habituelles. Le but sera d'en faire plus avec moins par la conservation des ressources et la rationalisation des matériaux. Les méthodes qui permettront d'y arriver sont :

- Intégration des systèmes, en utilisant moins de composants mieux intégrés
- Valeur optimisée, en remplaçant la qualité par la quantité, et les matériaux par l'information
- Planification du cycle de vie, en utilisant des matériaux durables, réutilisables et recyclables
- Réduction au minimum des incidences environnementales tout au long du cycle de vie

Les résultats de cette étude montrent clairement que l'utilisation d'acier en construction résidentielle est une solution en faveur de la durabilité, parce que l'acier permet d'en faire plus avec moins, de réduire la consommation de ressources et d'énergie, et qu'il constitue un système de construction plus durable et polyvalent que le bois. L'application plus répandue de l'acier en construction résidentielle devrait favoriser la transition de la croissance économique vers les aménagements de qualité, pour une industrie du logement durable.

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INTRODUCTION

Need for change

Of all forms of technology, residential construction is the most conservative and the less prone to innovation. The concept of housing is related to an array of subjective factors such as images of traditions, social symbols, historical, and cultural identities. It has evolved far beyond the basic human need for protection against the outside world. Residential building technology and material reflect the local culture and building tradition, for example: wood in North America, bricks in Europe, or concrete blocks in developing countries.

Globalization and competition have driven most other major technologies, such as cars, planes or computers, to universal standardization, decrease of production costs and increase of efficiency. This is also true for the industrial and commercial (IC) building industry, which is becoming increasingly competitive, global, and productive.

The residential, single-family construction sector has not similarly evolved, even in the context of the highly developed North American economy. Traditions and cultures are resisting technological change. In Canada, residential construction techniques are still largely based on custom-made, built on-site wood framing. Nevertheless, other materials and building method are worth consideration, and in the near future, may displace wood framing as the main construction method. One of the most promising technique for residential construction is the integration of structural steel frame and prefabricated building elements known as the metal building system.

Scope

A structural steel house uses a method radically different from the light gauge steel framing system.

- A light gauge steel house uses steel elements instead of wood framing members. The construction method is virtually the same and is a mere shift from wood to steel, whereas a structural steel house applies the technology of metal building system to residential construction.
- In a light gauge steel building, the walls are load-bearing, in a structural steel house, the structural frame is distinct from the envelope.
- A light gauge steel house is usually built on-site, as in traditional wood framing construction, whereas, a structural steel house may be designed, engineered, and pre-fabricated in a plant, and then shipped to the site for assembly.

This report does not address light gauge framing system for which other CMHC studies exist.

The report uses the term *steel house* to designate a structural steel house defined as a steel house where the *frame* and the *envelope* are distinct but integrated to form a *building system*.

Structural frame

In a steel house, the frame is distinct from the walls and supports all the loads. The frame is made with heavy (sometimes called *red*) standard steel elements, such as wide-flange beams, I beams, and hollow structural profiles. The most common structural arrangements are post-and-beams and portal frames. Multi-storey houses usually use concrete floors on steel decks.

Envelope

The envelope of structural steel houses is non-load bearing and light. and may be made with a modular, pre-fabricated panels and windows attached to the structure. The roof can use the same technique or a standing seam metal roof system.

Building system

The frame and the envelope form a system and are designed to work together for efficiency, fast assembly, and economy. The same company can design, engineer, manufacture and assemble the whole building.

Barriers and challenges

Conservative attitudes create barriers that prevent a wider acceptance of steel technology for housing. Many objective and subjective factors influence today's housing market. The bottom line is that though the new technology is beneficial, there is risk involved in the change.

Objective barriers

Prefabrication and building systems allow better control of quality and cost because the centraiization of responsibility permits close assessment of building costs. Faster construction means faster occupancy and faster pay back. Furthermore, steel houses last longer and keep their value. Yet,, financing non-traditional house construction is difficult, for, the banks do not like to take risks and seldom finance "experimental" architecture.

Subjective barriers

The residential market is image driven. The rationalism of industrial architecture (farms, commercial, industrial) disappears in housing. A home is a dream support, an out-of-work place, a symbol of success, a sign of good taste, a membership to a social group, and an identity mirror. Architecture corresponds to regional styles and traditions.

A house is a home and users want it to feel *homely*. As a result, the housing industry, the designers, the contractors, and the real-estate agents are cautious to change, and therefore, take a conservative approach.

On the other hand, life style and attitude toward housing is changing due to increasingly keen economic, social, and environmental issues such as housing cost, lack of space, traffic congestion, indoor air quality, and sustainability. An example is the popular artist-loft studio that offers to young urban professionals an industrial looking, low cost shelter, in a central location, and with space flexibility.

Communication barriers

The public and many building professionals have misconceptions about steel and often perceive it as an industrial material that is cold, expensive, heavy, difficult to use, and prone to corrosion and lightning. To illustrate the challenge of communicating the advantage of steel to the public, Appendix B presents a list of questions and answers based on frequent inquiries by builders and home-owners about the use of steel in housing.

CHAPTER 1 - THE NEW AGE OF STEEL

Steel is entering a third era. The first era, in the 19th Century, saw the fast development of new technologies for mass-producing steel at low-cost. Once industry solved the technical problems of making mild steel in large furnaces, steel became the predominant construction material because of its strength, availability, workability, and low cost. The main market for steel was in heavy construction: ships, bridges, industrial buildings, and armaments.

The second epoch, spanning the 20th Century, saw an immense increase of productivity, which resulted in the development of new methods for mass-producing consumer goods made from steel. The creation of standards profiles increased the efficiency in the application of steel in heavy construction. Other advantageous properties of steel, such as ductility and weldability, made it the predominant material for the manufacturing of light equipment. As a result, the main market shifted from ships to cans, to appliances, and then to cars, with the auto industry becoming the largest consumer. This evolution progressed at the same rate as the technological advances in mechanization and engineering. Hereafter, a gigantic jump in productivity was made possible through computerization.

The third epoch, which started some 20 years ago, is now driven by environmental concerns. The aim is to minimize the environmental impact of mass-consumption and industrialization. The challenge is to create a sustainable economy, and to keep the technical and economical benefits gained through industrialization without capitalizing the environment of both the present and the future. The solutions toward sustainability are strongly related to technology development and will have a deep effect on the production, manufacturing, and use of steel. For example, the dead weight of a vehicle uses approximately 80% of the fuel consumed by a car, therefore reducing the car weight means increasing its efficiency. Light materials, such as aluminum, plastic and fiber-carbons, could in the future displace the steel out of the auto industry market. A new market for steel is, however, emerging. Steel is the most structurally efficient and recyclable of all construction material. For that reason, the new, sustainable, steel may become the key construction material of a new, sustainable, housing industry.

Signs of change

Today, a few houses are made with prefabricated steel. However, three recent trends in the construction industry have shown signs of radical change. The first sign is the *awakening of steel*, the second is the *rise of the metal building system*, and the third is *the mobile home boom*.

The awakening of steel

The $44 billion per year North American steel industry had a brutal awakening a couple of years ago when Ford Motor Co. started to study the car of the future with an *aluminum* body. Now, the steel industry is fighting back to gain new prospects in untapped and non-traditional markets such as the residential construction market. Members of steel industry created an alliance, *The New Steel*, and planned a hundred million dollars, five-year, advertising campaign (see Figure 1.) The steel industry strategy is to show that:

"Steel is here, it's back, it's new."

The promotion of the new steel stresses two key benefits of steel: strength and sustainability.

Figure 1: Steel Alliance Ad

The ad says:

"The strength of steel can be found not only in the structures it helps to build, but also in the natural resources it helps protect.

"Framing an average-size house with steel uses the equivalent of only six recycled cars. On the other hand, framing that same house with wood takes an acre of trees.

Steel also helps the environment because it's the most recycled material in the world. Last year alone we saved enough energy to meet the total electrical power needs of Los Angeles, Seattle, Dallas, Atlanta, Washington, D.C., and Detroit, combined.

"You've always trusted steel to protect you and your family. Now you can trust it to protect our environment.

The New Steel. Feel the strength."

Strength

"Steel is strong, withstands hurricanes, and protects your family."

In fact, steel is the strongest construction material currently available. Its strength over weight ratio is superior to wood or concrete as shown in Table 1. The strength of steel improved significantly over the last 25 years, due to substantial improvements in steelmaking and better knowledge on alloys. On May 1, 1997, a major Canadian mill, Algoma Steel Inc., announced a new standard grade for structural steel that increases its strength by 17% at no cost increase. This makes steel -as a building material for housing- more competitive than ever.

Table 1: Strength of main construction materials

	Average Density	**Service Strength (1)**	**Ratio (2)**	**Factor (3)**
Material	kg/m3	MPa	S/D	Steel
Steel	7,850	350	44.59	1.00
Engineered Wood	721	20	27.75	0.62
Wood	500	10	20.00	0.45
Concrete	2,400	40 (4)	16.67	0.37

(1) Strength used in engineering calculations.
(2) Strength / Density ratio
(3) Strength / Density in relation to steel. Steel = 1
(4) May vary according to specifications

Sustainability

"Steel is recycled, use less energy, save the forest, protect the environment."

The fact is that steel is the most recycled material in the world, more than glass and paper. Some steel products such as structural profiles are made from 100 percent recycled metal. Re-using steel not only saves raw resources but also reduces air and water pollution, as well as energy consumption. According to the Steel Recycling Institute (SRI) (See Chapter 5)

"By recycling, in a year, the steel industry saves the equivalent energy to power about 18 million households for a year. When one tonne of steel is recycled, 1,130 kg of iron ore, 634 kg of coal and 54 kg of limestone are conserved. By making recycling integral to steelmaking, the steel industry leads the buy-recycled effort. In 1996, more than 58 million tons of steel scrap were recycled, for a 65.2 percent overall recycling rate."

Table 2: Comparison of main construction material

	Steel	Concrete	Wood
Raw material origin	Iron ore, coal, limestone	Limestone, aggregate, sand, steel for reinforcement	Forest
Recycled material as input	Recycled steel	Flyash, crushed concrete, recycled steel.	N/A
Embodied energy	High to medium	Medium	Low
Indoor air quality impact	Very low	Low to medium (radon)	Medium (Glue, wood preservers)
Recyclable into	New steel	Aggregate	Fuel
Reusability	High	None	Low
Construction waste	No	High (forms)	High (cuts)
Life Span	Long (if protected from corrosion)	Long to medium depending on permeability and quality of concrete	Medium to low depending on protection against moisture and pest.
Structural resistance	High	Medium	Low
Allow Flexible space	Yes, easy	Medium difficulty	Difficult

Table 2 compares the properties of steel, concrete and wood.

There are clear evidences of the awakening of steel in residential construction. Steel studs are increasingly becoming an acceptable alternative to the traditional wood frame. According to the American Iron and Steel Industries (AISI):

"Builders across the United States and Canada are constructing all types of steel-framed homes... An estimated 125,000 homes were built in 1995 with steel framing. By the year 2000, an estimated 25 percent of all new homes built in the United States will be framed in steel."

Another piece of evidence is the increasing application of steel roofing and siding in residential construction. According to the Metal Building Manufacturer Association (MBMA.)

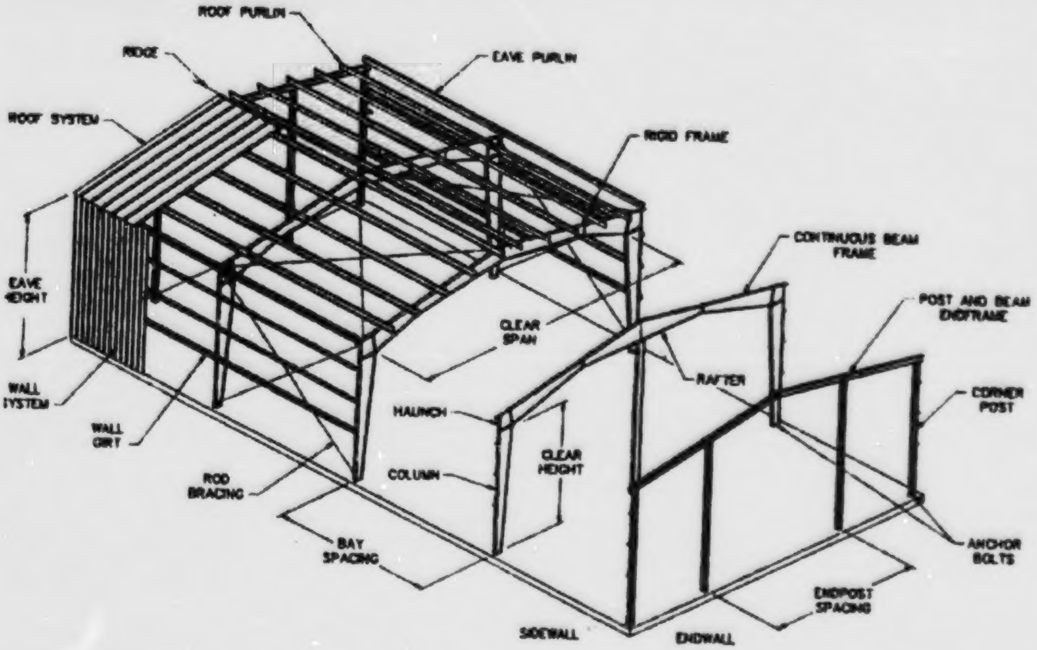
"Metal standing seam roofing for both new and retrofit applications is the fastest-growing market segment in the industry. Metal re-roofing systems will soon become a billion-square-foot-per-year market. ...Life cycle cost analyses that take into account the long-term,

low-maintenance features of standing seam roofs are proving them to be the best solution for most ...roofing problems."

Economics of steel

Steel's sudden growth in residential popularity has been fueled by both economic and environmental considerations in the building industry. Steel's value, when compared to its competitors, makes it the material of choice for most industrial and consumer applications. When adjusted for inflation, steel's price has remained virtually unchanged over the past decade, while prices for competing materials have skyrocketed.

Figure 2: Metal building system



According to the AISI:

"Such price stability has helped steel achieve new heights in the residential construction market. When combined with world-class quality, it has also enhanced the international competitiveness of steel's customers -- North American producers of automotive products, capital goods, construction equipment, appliances and packaging."

The rise of metal building systems

Steel requires preliminary planning and design that leads logically to prefabrication and systematic operation. Metal prefabricated building appeared at the end of the 19th century and experienced a growing success through various phases and continuous improvements. The metal building industry evolved from the concept of prefabricated building, to pre-engineered, to systems.

- Prefabrication means that some elements are built in a factory instead of on site, with the elements designed on a case-by-case basis and independently from the others.

- In a pre-engineered building, prefabricated elements are made from a few standard designs and have a limited number of off-the-shelf configurations.
- A system is, by definition, an assembly of interdependent elements forming a unified whole. In a metal building system, the components such as walls, roofs, primary and secondary framing, bracing and fasteners are designed to work together. A building system offers the additional advantages of a better integration of the elements of the building, lower cost and faster and easier assembly. (See Figure 2)

Standardization together with the rapid progress of computer design produced a metal building boom in the sixties. The success of the metal building systems for commercial and industrial application is tied closely to their cost-effectiveness, ease of assembly, fast construction, end-use flexibility, together with diversification in design and appearance. Building systems offer the additional advantage of a design-built process, which gives to one supplier single-source responsibility for project design, engineering, pricing, and construction. Today, low cost computer programs speed up the process of calculating, drafting, fabricating, and erecting elements, making building systems more efficient and more competitive than ever.

According to the Metal Building Manufacturers Association (MBMA):

"Metal building systems dominate the low-rise non-residential market. Pre-engineering steel structure comprised 65 percent of all new one and two-story buildings".

In other parts of the world, as in the UK, the statistics are similar. According to the SCI,

"In the UK, steel enjoys the highest market share in the world in the most important construction sectors: Commercial buildings - 57 percent, Industrial buildings - 95 percent."

In the US, some metal building system suppliers are attempting to penetrate the residential market, directly or via affiliate companies. Amongst others, *Excalibur*, *Classic Steel home*, and *Tri-Steel*, already sell and install prefabricated steel system for single-family housing.

The mobile home boom

In North America (especially in the USA), a growing number of people are buying factory-built houses. They have the choice between various types such as:

Figure 3: Manufactured Home

- Manufactured home: A home built entirely in the factory in single or multiple sections, transported to the site and installed. (The former name was mobile home.)
- Panelized home: Factory-built homes in which panels, a whole wall with windows, doors, wiring, and outside sidings are transported to the site and assembled.
- Pre-cut home: Factory-built housing in which building materials are first factory-cut to design specifications, then transported to the site, and finally assembled. Pre-cut homes include kit, log, and dome homes.

According to the Manufactured Housing Institute (MHI), manufactured housing represented 30 percent of all new single-family build homes started in 1997. The top 25 US manufacturers sold 322,582 homes for a total of approximately 8 billions US Dollars. The MHI attributes these favorable trends for manufactured homes in the U.S. to various factors:

- Aging baby boomer population.
- Generation "X" population moving into first time home buying market.
- Substantial cost savings up to 50 percent versus site built housing. For example, a turnkey manufactured house of 150 m2 (1,600 ft^2) sells for U$ 55,000 or C$518 /$m^2$ (C$48/ ft^2 C$516/m^2).
- Design improvements away from former *boxy* style.
- Population shift towards suburban and rural areas - traditionally strong areas for manufactured housing.
- Increased ability to install manufactured homes in subdivisions using experienced developers.
- Houses losing their investment appeal and consumers satisfied with more modest housing.

New challenge

The new steel, the rise of building systems and the mobile home boom are three trends indicating a shift in the building market toward building systems, modularity, and pre-manufacturing, using sustainable, recyclable steel. The application of these new concepts to residential construction involves:

- The use of industrial materials (mainly steel and concrete) rationally chosen for their physical and environmental properties, ease of construction, and cost, rather than for their traditional meaning.
- A functional and flexible design to allow future changes in space and usage.
- The prefabrication and standardization of building elements to reduce cost and improve quality.
- A fast construction method to reduce financial charges and to allow occupancy in the shortest period of time.

Yet, the application of steel system building to residential construction meets some obstacles:

- Steel is not yet accepted by residential contractors.
- An industrial metal building is not a house, considering the difference in need and functions.
- A manufactured home has restrictions in terms of size and zoning and is still considered a low-end product.
- The influence of tradition and socio-cultural functions is very strong.

Therefore, the challenge is:

(1) how to apply the rational and cost-effective techniques of the prefabricated steel building system to residential construction,

(2) while maintaining the physiological and socio-cultural characteristics of housing?

As shown in Chapter 2, all buildings are systems. By design, some systems arrive to a desired result more efficiently than others. Chapter 3 examines more than 150 steel houses, built during the last 60 years. It shows that these houses are efficient building systems, that provide adequate housing functions and which are well accepted by the users. It also outlines the main obstacles for implementing the technology in the housing market.

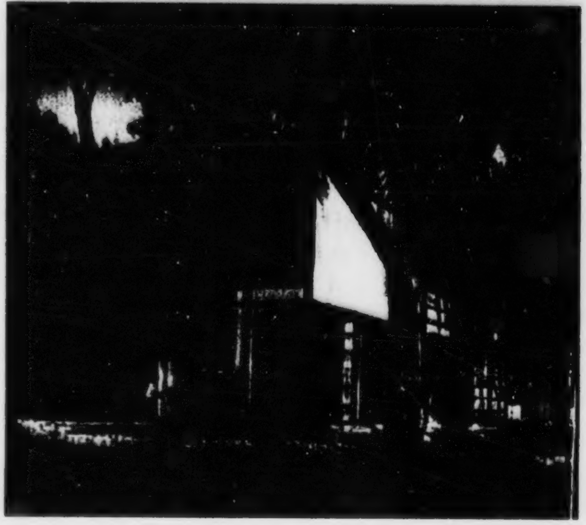
Modern architecture

Building houses with a steel skeleton is a rational approach that is often associated with modern architecture, functionalism, minimalism, or "International Style." The concept of modern architecture is well summarized in "Toward a New Architecture", a manifest for mass production houses written by the French architect "Le Corbusier" in 1931:

"Industry, overwhelming us like a flood that rolls on towards its destined ends, has furnished us with new tools adapted to this new epoch... We must create the mass-production spirit.

The spirit of constructing mass-production houses. The spirit of living in mass-production houses. The spirit of conceiving in mass-production houses ... we shall arrive at the "House-machine," the mass-production house, healthy and beautiful in the same way that the working tools and instruments which accompany our existence are beautiful."

Figure 4: Modern Steel House



Many steel house architects followed this idea. Craig Ellwood, the designer of many steel houses, declared:

"Our economy dictates that machine products and machine techniques be the essence of our building."

Structural steel implies prefabrication and industrialization, which is highly compatible with the concepts of modern architecture. Structural steel frees from loads the external and internal walls and permits the most characteristic expressions of modern architecture: open, flexible internal spaces, and glass walls.

"If there is one system that has revolutionized our thinking about ways of building it is the skeletal frame, and if there is one material that has dominated frame construction it is mild steel. It is also the material on which, following the example of Mies, many architects have developed their own philosophy of building." (Architecture & Construction in Steel. Steel - Construction Institute.)

The motives behind the *philosophy of modern architecture* are to build houses in a rational and systematic way, and to create living spaces well suited to human needs. Numerous examples of completed projects show that these two objectives are not incompatible.

CHAPTER 2 - BUILDING SYSTEMS

A steel house is an economically sound and ecologically conscious response to housing needs because it is an efficient building system. The demonstration of this statement needs a definition of building systems and will use concepts developed by Richard Rush in his book "*The Building Systems Integration Handbook*". (See bibliography)

System

The main concept is that a building is a system. A system is normally defined as a coherent set of elements organized for a particular purpose, with the whole being more than the sum of its elements or sometimes, the result being a completely new product. For example, a microchip is different from the silicon waffles it contains, just as a building is much more than the simple assemblage of building material. A building is an assembly of interdependent elements with a particular purpose, and therefore, it is a system, or more precisely, a building system.

Not all systems are created equal. Some are "smarter" than others and achieve a desired result more efficiently. The difference is in the design, in the ability of each element to achieve a particular function, and in the level of integration that is the way the parts are put to work together. Integration translates into efficiency, which itself translates into economy of means and doing more with less.

Likewise, some building systems perform better than others and achieve their desired objectives more economically and with less resources. The question is, what constitutes an efficient building system?

The concept of building system presented in Figure 5 provides a methodology for answering to that question. This diagram is two-dimensional and shows:

- From bottom to top, the successive layers of requirements, goals, restrictions that form the design criteria of the building.
- From left to right, the life-cycle of the building system from design and construction, to its intended life, and to the end of its life.

At the bottom are the physical and material constraints defined by the limit to the amount of resources available for constructing and operating the building. The economical use of resources will make the project feasible.

In addition of being feasible, the building must be acceptable by the users and must respond to complex human needs, such as health, safety, esthetics, and community status.

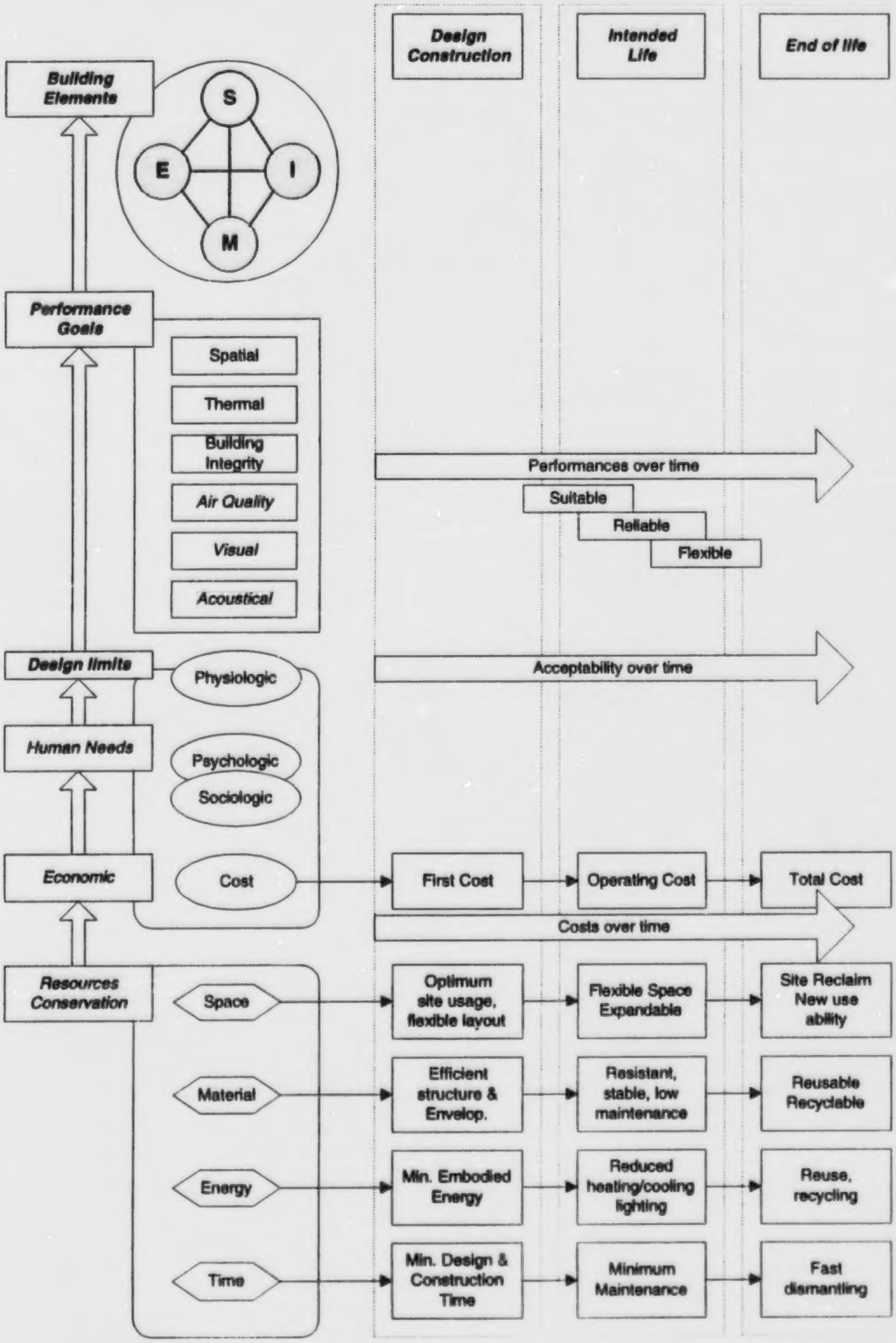
These human needs can be translated into performance goals to provide adequate space, and thermal comfort.

Finally, at the top of this chain of requirements is the building system composed of sub-elements that are arranged and integrated to meet the performance goals.

Chapter 3 analyzes numerous cases of existing steel houses and examine how they stand against these criteria, how they satisfy these needs, and how they perform. Consequently, Chapter 3 will outline that:

1. A steel house optimizes the use of resources and is, therefore, economical.
2. A steel house satisfies human, social and cultural needs.
3. A steel house has superior performance.

Figure 5. Building System Diagram



Sub-systems

A building is made of many elements. The design and building process is in most cases the effort of a team of professionals that apply their expertise to only a part of the whole building. Hence, the building is often designed and built in parts. As shown at the top-left of the graphic, those parts may be defined as four sub-systems: structure, envelope, mechanical and interior. Each building sub-system provides a specific function to the building and, in traditional construction, often corresponds to a specific trade and professional expertise. The four subsystems are: the structure, the envelope, the mechanical system, and the interior. Their level of integration will determine the efficiency of the complete system.

S: Structure

The structure must balance a range of forces. Natural forces - such as gravity, wind, snow, seismic - and programmatic (live) loads are based on the building use.

⇒ In traditional housing construction, the structure is the wood framing, usually assembled by the contractor, often leading to oversize and waste of construction material.

⇒ In a metal building system, the structure is determined and optimized by the calculation of the structural engineer.

E: Envelope

The envelope must respond to natural elements, such as rain, wind, sun, heat and cold as well as to human values, such as safety, security and social image. The envelope includes the siding, the stucco, the windows, and the roofing.

⇒ In traditional construction, a succession of sub-contractors working independently from each other, add gradually these elements to the building. The result is a low level of integration.

⇒ In a metal building system, all the elements of the envelope can be integrated into a single panel system attached to the structure. The result is a much higher level of integration and greater efficiency.

M: Mechanical

The mechanical system must resolve the specific needs of energy, air and water supply, waste disposal, heating, cooling, and lighting.

⇒ In traditional housing construction, various trades install the plumbing, electrical, and heating system, leading to a poor level of integration between these sub-systems.

⇒ In a metal building system, these elements can be pre-manufactured and integrated with the rest of the building.

I: Interior.

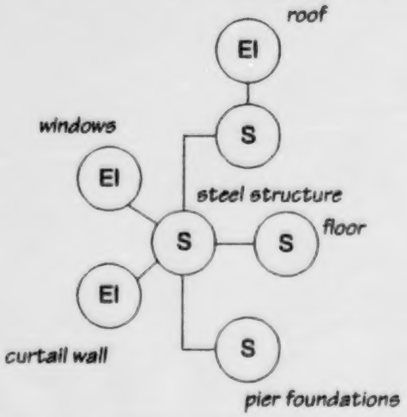
The interior must respond to direct human demand on the building and provide comfort and support for human activities.

⇒ In traditional housing construction, a series of sub-contractors install the insulation, vapor barriers, drywall, and finishing. The lack of integration often makes this part the most expensive of the building process.

⇒ In a metal building system, the curtain wall already contains the insulation and sometimes the interior finishing, leading to a much higher level of integration.

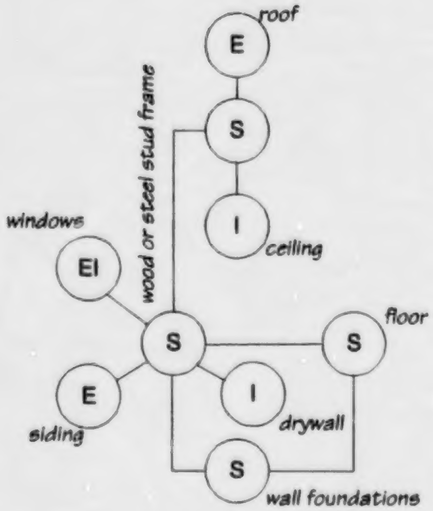
Subsystem of steel houses

Figure 6: Structural steel building system



S: Structure, E: Exterior, I: Interior

Figure 7: Wood or steel stud frame building system



Compared to a traditional framed wall construction, a steel building system offers the possibility of much greater integration between the three main elements: envelope, structure, and interior.

⇒ In a traditional wood-frame house, the studs in the wall form a structure enclosed inside the envelope and the drywall. It forms a 3-parts system.

⇒ In a steel house, the steel frame forms the structure and an independent curtain wall supplies both the exterior siding and interior wall functions. Therefore, a steel house has only two distinct elements: combined envelope/interior/curtain wall and structure.

Figure 6 and 7 shows the interaction between the various sub-systems and their level of integration. A steel house has a greater level of integration and has fewer components, especially when the steel is left exposed. Using steel in housing means, therefore, a more efficient use of resources and a lower cost. The results of the case studies in Chapter 3 corroborate this claim.

Performances mandates

Human needs are a complex mix of physiological, psychological, and sociological needs. How much a building satisfies these needs can be measured by looking at six basic performance mandates:

1. Spatial

The building system must provide spaces to support individual activities, aggregation of spaces to support activities as a whole, and connection of spaces to support circulation and transportation of people, goods, and services.

2. Thermal

The building system must provide thermal comfort by controlling the air temperature, the radiant temperature, the relative humidity, and the air movement.

3. Building Integrity

The building system must withstand external and internal forces and stresses over time.

4. Air Quality

The building system must provide air quality and prevent pollution related to building material, surrounding ground and water, outdoor pollutants, indoor activities, and the use of chemicals.

5. Acoustical

The building system must provide acoustical privacy from both inside and outside.

6. Visual

The building system must provide adequate lighting according to occupancy functions.

Performance of steel houses

The importance of these mandates may vary according to the type of buildings. For single-family housing, the most important are the first four. (Spatial, thermal, building integrity, and air quality) Chapter 3 shows that a steel house not only meets all these criteria, but also matches or exceeds the performances of a traditional wood house.

Human needs.

Meeting the physiological, psychological, sociological side of human needs makes the building "acceptable" by the user and the society, which is also one of the key objective of the housing market. The physiological side is fundamental because it is related to the physical well being of the user who needs health, safety, comfort, temperature, fresh air, fire safety, and so on. The psychological and socio-cultural aspects are more complex and difficult to define because they are related to the society and the human behavior. They are, however, equally important. Psychological needs include the support for individual mental health, such as privacy, clarity, image, and change. The sociological or

Table 3: Performance criteria versus human needs

	Physiological needs	**Psychological needs**	**Sociological needs**
Spatial	ergonomic comfort	habitability, beauty, calm	setting
Thermal	thermal comfort.	sense of warm, individual control.	
Integrity	fire and structural safety,weatherproof,	sense of stability, durability.	status, appearance, craftsmanship
Air Quality	air renewal, no toxic outgassing, no radon.	airy spaces, not closed in, not stuffy.	no smoke, odour from outside.
Acoustical	acoustical comfort.	quiet, soothing	privacy, no noise from outside
Visual	good lighting, natural lighting.	orientation, intimate, sense of space	sense of territory?
Common to all	physical comfort health safety functional appropriateness	psychological comfort mental health esthetics delight	privacy security community image/status

Source: The building system integration handbook. R. Rush.

socio-cultural needs refer to the well being of the community and relate the individual to the group. It includes esthetics, social recognition, social image, and communal behavior.

The relation between human needs and performance criteria is cross-referenced in Table 3.

These needs form the basis for defining the acceptability of a building.

Acceptability of steel houses

Acceptability is an essential factor in the implementation of steel houses. A steel house may look exactly the same as a traditional house and if the steel is hidden, no one can tell the difference. Many steel houses, however, have a distinctive character, with exposed steel, large windows, and flexible open spaces. Chapter 3 gives many examples of good design for steel houses that were extremely well accepted by their users. Acceptability over time is also a very important factor, and as shown in the next chapter, a steel house lasts long and ages well.

Economical requirements

Acceptability alone is not enough. The project must also be feasible and is subject to economical criteria. Economical requirements are based on the availability (or scarcity) of financial, technical, and material resources and can be met by an efficient use of resources. Environmental responsiveness also requires resource efficiency. With the increasing focus on the environment and sustainability, many private and public initiatives have shown that conservation of resources increases the cost-efficiency of a project. Economy and environment are strongly related; resource efficiency means economy.

The greatest economic value of a building system resides in space, material, energy, and time. Therefore, the conservation opportunities of these four resources have the greatest saving potential.

Conservation Opportunities

Economy and cost saving opportunities exists not only at the construction stage, but also during the whole life cycle of the building, from cradle to grave to rebirth:

- during the design and construction stage, conservation of resources reduces the construction costs.
- during the intended life of the building, conservation of resources reduces operating & maintenance costs.
- At the end of the building life, there are opportunities for minimizing the deconstruction and waste costs by reusing, recycling, and therefore, conversing resources.

Table 4 outlines the conservation opportunities that exist for each major resource at each period of the building life cycle.

Feasibility of steel houses

The next chapter will demonstrate in more detail how a steel house meets or exceeds all objectives of Table 4.

Over the entire life cycle of a building, the use of structural steel offers many opportunities for controlling the costs by conserving valued resources.

Construction costs.

These costs occur during the design, engineering, fabrication and assembly of the building. They include the direct costs related to construction and the indirect costs related to the site and secondary services, such as marketing, financing, and licensing.

Operating costs

The operating costs are incurred during the intended life of the building. Direct operating costs are related to maintenance and energy consumption for heating, cooling, ventilation and lighting. Indirect operating costs are generated by unexpected changes in the building function or usage.

Table 4: Major conservation opportunities during the lifetime of a building system

	Design & Construction	**Intended lifetime**	**After-life**
Resources	**Construction Costs**	**Operating Costs**	**Residual Costs**
Space	Optimization of site use, internal layout and envelope ratio.	Design of open, flexible internal space adaptable to a wide range of future use. Design for easy building expansion.	Design of reusable building. Minimization of building impact on the ground for easy site reclamation.
Material	Selection of the most efficient structure and envelope system. Use of recycled material	Use stable material, resistant over time and requiring low maintenance.	Reuse and recycle of building materials.
Energy	Reduction in energy embodied in building materials and reduction of energy consumption during construction and transport of material.	Reduction in heating, cooling, lighting and electricity requirements	Recycling and reuse of embodied energy.
Time	Reduction of design and construction time. Prefabrication, pre-manufacturing, fast-tracking.	Reduction of maintenance time.	Easy to dismount, restore or reassemble.

Residual costs

These costs occur at the end of the life cycle of a building and include demolition, land reclamation, environmental rehabilitation, and waste disposal. Today, the construction industry very seldom takes in account these end costs. However, there is an increasing trend to assess the total costs of a building during its whole life cycle and the use of Total Cost Assessment methodology (TCA.)

Ecological requirements

An emerging global perspective sees the economy not in isolation, but rather as an integrated and dependent part of the ecosphere. In this context, there is an increasing necessity for assessing the environmental performance of buildings. The Green Building Challenge, initiated by Natural Resources Canada (NRCan), has developed a method for measuring the performance of green buildings, called the Green Building Tool. (GBTool) The GBTool analyzes the environmental issues through six performance area:

- resource use,
- ecological loading,
- indoor environmental quality,
- longevity,
- process, and
- context.

This "green" tool set offers criteria that are not radically different to the economic requirements listed before. It rather puts them under the perspective of the ecology.

While the first four categories are self-explanatory and are already included in the economical requirements of conserving resources, the last two, *process* and *context*, need further explanation:

Process includes issues related to the structuring of the design team and operations and maintenance practice. Including the environmental performance criteria as early as possible in the design criteria and having structural and mechanical professional involved in the preliminary decisions will result in a better integration of green features into the building system.

Context issues include site selection, building location, and proximity to amenities. This criterion acknowledges the potential high demands of the land and the environment created by new development. It is somewhat related to the economical requirement of space conservation.

Summary

In summary, a building is defined as

(1) an assembly of elements integrated for a purpose
(2) that must correspond to performance mandates
(3) dictated by physiological needs,
(4) within the design limit of psycho- and sociological acceptability, and
(5) within the design limit of economic feasibility,
(6) which is achieved by the conservation of resources
(7) over the life-cycle of the building.

The efficiency of a building system is a measure of its ability to deliver the required performance over time while using resources efficiently.

From the above list of definitions, conservation of resources over time (6) & (7) are the key requirements that underlie the feasibility and efficiency of the building system over its entire life cycle. Furthermore, aiming at conserving resources leads to green, sustainable buildings.

Effectiveness of steel houses

Chapter 3 analyzes more than 150 structural steel houses built during the 20th century. These examples show that the main reason for using steel in housing is the rational use of resources. Steel houses provide the most flexible living space with fewer amounts of material, energy, time, and money.

CHAPTER 3 - CASE STUDY

Structural steel in housing is certainly not a new idea. During the 20th century, many designers preferred this technology to other methods of construction such as wood, bricks or concrete. Table A-1 in Appendix A presents a comprehensive inventory of 158 steel houses built during the 20th century. The study of these examples, in the context of the building system approach provides clear evidence of the ability of steel to deliver the performance required in housing while using resources effectively.

According to the concept of building systems developed in the previous chapter, the effectiveness of a building is the function of following criteria:

- **Feasibility**: To be feasible and economical, the building must minimize the use of resources during its lifetime.
- **Acceptability**: To be acceptable by the users and the society, the building must meet psychological and socio-cultural human needs.
- **Performance**: To meet the criteria of acceptability, the building must offer good spatial, thermal, safety, health, acoustical, and visual performances.
- **Integration**: To answer efficiently to the performance mandates, the building must have a high level of integration between its elements.

This chapter shows how steel houses meet these criteria by presenting the results of an in-depth study of the steel houses inventoried in the Table A-1 of Appendix A. It will use these examples as the basis for asserting four reasons why a steel house is an efficient and effective building system:

- **Reason #1:** Steel houses are cost-effective because they conserve resources
- **Reason #2:** Both users and owners of steel houses are extremely satisfied and steel houses are well accepted by the users.
- **Reason #3:** Steel houses perform equally or better than any other types of construction.
- **Reason #4:** Steel houses have a high level of integration of their elements.

At the same time, the analysis of existing case studies identified two main barriers to the wider application of steel technology in the housing market

- **Barrier #1:** Steel house technology requires a mind change of the many professionals and officials involved in residential construction.
- **Barrier #2:** The production of steel house requires a design-built approach, which is not a current practice in the home building industry.

Appendix A develops a more detailed discussion on the advantages of steel by comparing the case study steel houses to the above criteria, while this chapter summarizes the main findings. Further information on these houses is available in the reference documents indicated in the bibliography.

Cost-effectiveness

Reason #1: Steel houses are cost-effective because they conserve resources

The conservation of resources offers the opportunity of low cost construction. As described in the previous chapter, the resources with the highest value in a building system are space, material, energy, and time.

Table 5 summarizes the conservation opportunities for each resource over the entire life cycle of a building. The details are developed in the following sections.

Table 5: Cost reduction and conservation of resources opportunities resulting from the use of structural steel

Resources	First Costs (Construction)	Operating Costs (Intended life-time)	End costs (End of life)
Space	Building on difficult sites Small footprint Addition to existing building Open, self-standing internal space easy to finish. Do-it-yourself finishing work.	Flexible space easy to renovate, transform, enlarge and resale.	Easy land reclamation. New use for building.
Material	Efficient use of material Structural efficiency. Use of concrete floors. Waste reduction during construction. Small foundations. Light envelope.	Stable material Resist to time. Non-combustible, rot & insect - proof. Low maintenance.	Reusable elements Recyclable material. Waste reduction.
Energy	Optimization of material use by structural optimization means less embodied energy	Elimination of thermal bridges by use of walls with higher insulation value. Application of passive solar energy system. Large windows for day lighting.	Recuperation of embodied energy by reuse or recycling of steel material
Time	Increase in productivity. Reduction of site work. Fast construction. Low skill requirements. Do-it-yourself assembly. Elimination of scaffolding. Low site overhead. Short financing period.	Fast occupancy. Low maintenance overhead.	Reduction of labor-cost during the life cycle of the building. Faster land reclamation.

Appendix A, section 1, presents many examples of steel houses built at low-cost:

Space

Space is a limited and expensive resource. Property cost, site preparation, interior area and layout have a large influence on the total building cost. In relation to space, the use of structural steel brings the following cost reduction opportunities.

a) First costs

- *Land and site costs.*

  Steel makes it possible to build on difficult sites and steep hillsides, which are often cheaper. Once built, however, they become view properties and their values increase significantly. (See Appendix A, 2.1.)

  Steel allows for "touching the ground lightly" using pier or pile foundations, and therefore, causing less interference with the site than wall or slab foundations would have. (See Appendix A, 2.2.).

  In downtown cities, where land is more expensive, steel allows additions to older structures, rooftop buildings, or infills. Light, prefabricated steel opens possibilities to build in remote, insular and cheaper sites. (See Appendix A, 2.3.)

- *Interior finishing costs.*

  The wide span of structural steel allows for open, empty, flexible interior space and the use of low-cost prefabricated partitions, cabinets-walls or moveable partitions. (See Appendix A, 2.4.)

A self-standing structure allows do-it-yourself finishing work by the user with potential saving advantages. (See Appendix A, 2.5.)

b) Operating costs

- *Renovation costs.*

  Successive home users may have varying needs: number of bedrooms, size of kitchen or addition of a home office. The long span of structural steel allows the flexibility of non-bearing interior and exterior wall and makes renovation less expensive and user-friendly. (See Appendix A, 2.4 & 2.5.)

- *Expansion costs.*

  Adding new portal frames and moving the prefabricated wall panels can economically expand prefabricated steel structure houses. (See Appendix A, 2.6.)

- *Marketing costs.*

  Flexible houses will appeal to a greater number of potential buyers. The recent trend in urban, open "loft-studio" indicates that flexibility sells and can reduce marketing costs.

c) End costs

- *Reclamation costs.*

  A steel structure can have a smaller footprint with pier foundations instead of perimeter foundations. Reclamation of land will hence be cheaper.

- *New use for the building.*

  The great flexibility of a structural steel house offers many opportunities for reusing the building at the end of its life cycle. A prefabricated house can be dismantled and re-assembled elsewhere. (See Appendix A, 3.4.)

Material

Material is a limited and costly resource. The type, strength, stability, weight, complexity, durability, maintainability, and recyclability of building material affect the cost of building over its whole life-cycle. The use of steel provides many opportunities for reducing the consumption of material in the lifetime of a building and thus, for reducing costs.

a) First costs

- *Material costs.*

  Steel is the most efficient structural material. Sophisticated computer programs allow the optimization of elements and reduces the material cost to a minimum. Standardization and prefabrication further reduce the cost of construction (See Appendix A, 3.1 to 3.3.).

  Relieved from structural loads, the other parts of the house, that is the envelope and the interior, can be made with light, standard, prefabricated, and economical materials. This results in substantial saving during the pre-manufacturing and assembly of walls, windows and partition. (See Appendix A, 3.6.)

- *Waste costs.*

  Waste costs money. Through prefabrication and the rational use of material, steel promotes the reduction of waste during manufacturing and assembly and therefore the reduction in the costs of material, transportation, and disposal. (See Appendix A, 3.4.)

Foundation costs.

A house built with structural steel is lighter and can touch the ground at a fewer points, on smaller, concentrated foundations. The net result is a compound saving on foundation costs: excavation, forming, reinforcing, labor, concrete, and backfill. (See Appendix A, 2.2 and 3.6.)

b) Operating costs

- *Repair costs.*

  Steel is a stable material; it does not warp, shrink, or change size. The walls of a steel house stay true, do not crack and are less likely to require post-construction repairs.
  (See Appendix A, 3.1.)

Maintenance costs.

Steel does not rot nor get attacked by insect and fungi. Properly primed steel located inside the envelope is virtually corrosion- and maintenance-free. (See Appendix A, 3.1. & 4.2.)

c) End costs

- *Benefits from residual value.*

  A steel house will always keep a residual value. The steel elements can be resold and put to other structural uses. Alternatively, the steel can be recycled to make new steel. (See Appendix A, 3.4.)

- *Waste disposal costs.*

  The elements of a prefabricated building can be dismantled, reused or recycled instead of being demolished and wasted. (See Appendix A, 3.4.)

Energy

Energy is a limited, costly resource that has far-reaching implications in the context of sustainability. The use of steel raises two issues on energy:

Table 6: Thermal conductivity of common construction materials

	Conductivity W/ m K	Ratio to Steel
Steel	80	1.000
Aluminum	273	3.413
Wood	0.14	0.002
Concrete	1.1	0.014
The lowest conductivity value means the highest insulation		

Embodied energy

Steelmaking, rolling and manufacturing are energy-intensive, and the *embodied energy*, or the energy used during the fabrication, of the steel elements is relatively high. With the increasing price of energy and pressing energy related problems such as global warming and air pollution, the cost of embodied energy and pollution in construction material is becoming increasingly important. Nevertheless, cost accounting of energy expended during construction is very seldom accounted for in the building industry.

Thermal Conductivity

Steel conducts heat more than wood or concrete. (See Table 6.) The penetration of the envelope by a conducting material such as steel causes heat losses and condensation by thermal bridging.

Notwithstanding these drawbacks, a properly designed steel house can meet energy efficiency standards.

a) First costs

Energy costs

Energy consumption of modern steelmaking arc furnaces has decreased by a factor 2 over the last 30 years and continues to improve. The newest arc furnaces are now able to process 100 percent scrap metal into new structural members, thereby reducing the amount of energy consumed in the extraction of raw materials and in the primary production of iron.

The rational use of structural steel and prefabricated building material significantly reduces the cost of energy consumed for the fabrication, transportation, and assembly of the house elements. Progress in computer technology has permitted the optimization of the steel structure and the reduction of the amount of material and energy used in a building. (See Appendix A, 4.1.)

b) Operating costs

Heating costs

When the steel frame is completely contained in the envelope, a steel house can have a high thermal efficiency. The envelope insulates the skeleton from the outside temperature, eliminates thermal bridges and condensation, and protects the steel from corrosion. A steel structure makes the structural elements in the walls redundant and eliminates the need for wood or steel studs. Studs, whether made with steel or wood, are thermal bridges. The walls can be made with highly efficient insulated panels, thereby providing superior insulation and reducing the heating and cooling costs. (See Appendix A, 4.2.)

Structural steel allows the use of concrete floor, which together with large south-facing windows can form an efficient passive solar energy system and reduce heating costs. (See Appendix A, 4.3.)

- *Lighting costs*

  A self-standing structure permits large windows with the benefit of natural daylight. (See Appendix A, 3.6. *Glass houses*)

c) End costs

- *Reuse & recycling.*

  The reuse and recycling of structural steel can significantly reduce the energy spent in new steel.

Time

Time is money. Time-related activities such as labour, maintenance, financing, vacancy, and marketability have the greatest effect on the total cost of a building and over its total life cycle.

a) First costs

Speed of construction has a compounding effect on the total cost of the building:

- *Increase in productivity*

  Labor is the greatest cost factor in a building. The use of structural steel shifts the operations from the site to the factory and creates better economic, ergonomic and environmental work conditions. The movement of building materials can be more efficient with lower transportation, handling and stocking costs. (See Appendix A, 5.1.)

- *Site labor costs*

  Site construction is faster and is less affected by weather. The assembly of prefabricated elements requires less skill than carpentry and may even be performed by the owner. In a short period of time, the building can be closed and ready for finishing works or partial occupancy. For construction on remote sites, the crew transportation costs and per diem are significantly reduced. (See Appendix A, 5.2.)

Reduction of building cost by pre-fabrication

The benefit of prefabrication may also apply to the other elements of the building system, envelope, mechanical and interior equipment. Separately, each element can be made in an industrial environment with a greater control on cost, time, and quality. It can then be shipped to the site for assembly. Together, the integration of the four elements described in Chapter 3 brings even greater benefits. Table 7 shows the main opportunities for conservation of resources resulting from prefabrication of the other elements of the building. (See Appendix A, 5.2.)

Table 7: Major conservation opportunities of building elements

Elements	Space	Material	Energy	Time
Structural Prefabricated structural steel frame	Allow building on difficult sites. Easy to transport on remote locations.	No waste on site, lightness, reuse, recycle.	Reduction in embodied energy, reuse, recycle.	Fabrication in controlled conditions. Fast assembly of structure.
Envelop Prefabricated wall panel, glass panels and windows	Allow building on difficult sites Easy to transport on remote locations.	No waste on site, lightness, any foundation walls. Reuse.	No thermal bridge through structural elements in wall.	Fabrication in controlled conditions. Fast assembly
Mechanical Prefabricated self-contained heating unit. Prefabricated self-contained bathrooms.	No need for special room. Units may be installed outside the building.	Less waste, compact units.	More efficient compact units.	Fabrication in controlled conditions. Fast installation
Interior Prefabricated partitions and cabinet-walls	Flexibility, open plan.	Light no material waste on site. Reuse.	Reuse.	Fast installation of flexible, movable partitions,

- *Overhead costs*

  Reduction of site work means reduction of equipment rentals such as a crane, excavation equipment, scaffolding, and tools. The structure provides an immediate support for the installation of floor and roof decks, while the deck offers a support for installing the prefabricated wall panels and windows from inside, eliminating the need for scaffolding. Disruption of the street, the traffic, and the neighborhood can be reduced to a minimum.

- *Financial costs*

  Faster construction means shorter financing period and saving on interests.

b) Operating costs

- *Renovation, maintenance, expansion labour cost*

  For the same reasons described in the section "space", the inherent flexibility of a steel house reduces the labour cost of renovation, maintenance, expansion, and resale.
  (See Appendix A, 2.4.)

- *Vacancy costs*

  Prefabrication allows faster occupancy or partial occupancy.

c) End costs

Total reduction of labor cost

The methodical dismounting of a steel house is more labor-intensive than the demolition of a traditional house. The former method, however, allows the reuse or recycling of the elements and indirectly conserves the vast amount of time and labor spent during the whole lifetime of the building: extraction and transportation of resources, manufacturing of building elements, maintenance and repair. Therefore, the recyclability and reusability of steel reduce the total amount of time and labor spent in a house.

User acceptability

Reason #2: Steel houses are well accepted by the users

Housing reflects tradition, culture, image and social factors. Steel house may appear as non-traditional, hi-tech, unusual, or unkind. Nevertheless, building with steel does not necessarily mean repeating the same prefabricated monotonous box houses. High-tech manufacturing and computer technologies allow diversity and flexibility in forms and functions.

"The more advanced the technology, the cheaper it is to introduce variation in output. We can safely predict therefore, that when the construction industry catches up with manufacture in technological sophistication, gas stations, airport, and hotels, as well as supermarkets (not to mention housing) will stop looking as if they had been poured from the same mould. Uniformity will give way to diversity. " (Alvin Toffler, Future shock. Alvin and Heidi Toffler live in a steel house designed by Soriano and also own a second steel house remodeled by Ed Niles.)

The analysis of steel houses showed a vast diversity of design. Steel house may:

- be extremely simple, if not minimal such as the modernist Case Study Houses.(See Appendix A, introduction.)
- have a sculptural quality such as the house of Ed Niles, Arthur Erickson or Glenn Murcutt. (See Appendix A, 3.2. *complex forms*)
- be well-integrated in the site such as the houses sitting lightly in the Australian landscape, (See Appendix A, 2.2.)
- have a strong cultural link such as the Tatami house of Shimogamo, (See Appendix A, Table A-1 #156)
- look similar to a traditional house such as the prefabricated villas of "Sekishui House Inc." in Japan. (See Appendix A, 3.3.)

A common denominator of well-designed steel houses is that they make the user happy. The analysis of existing steel houses shows that once they have made the step, owners of steel houses do not want to come back:

"The one thing that has become apparent in visiting many of the (steel) houses, is that not one owner would live any other way". Neil Jackson, *in* "The Modern Steel house".

Large public interest

Some steel house were built as a prototype open to the public during World Fairs and exhibitions or they were experiments presented in a magazine as for the "Case Study House Program" in California. These houses always raised an enormous public interest and the open houses attracted a great number of visitors as described in Appendix A, section 6.1.

Barriers to a wider application

The above sections have shown the benefits of steel houses over traditional construction. The solution appears particularly attractive in a market with high demand for affordable housing near a highly developed industrial infrastructure. Yet, today, it is still a marginal technology. A major barrier is the relation between the professionals involved in the construction process: Architects, builders, developers, suppliers, manufacturers, engineers, and officials. These professionals must master the technology to make it an effective solution. This leads to the first barrier to overcome for a wider application of steel technology in the housing market.

Barrier #1: A wider application of steel house requires a mind change on the part of the building professionals

The analysis of built projects offers a good insight on these issues:

Architects and designers:

Steel needs planning, precise detailing and accurate control at each phase of the building process. The architects and designers need new planning skills as the decision process shifts upstream from the site to the drawing board (or the computer).

"*Each house is a new research problem. Few architects are willing to devote their live to a practice so unrewarding as the steel house. Indeed, few architects are eager to devote themselves to residential work. ...all details (must be) worked out precisely on the drawing board,...* " Esther Mc Coy, Case Study Houses.

Engineers

Steel needs the calculation and supervision of an engineer. The engineer needs to be closely involved in the process, otherwise his service becomes an additional cost to the building as well as a source of inefficiency:

"*We must not glorify undeliberately the engineer who must put his knowledge to the service of the architect, but what architect, if he is not one himself.*" Jean Prouvé.

Contractors:

Steel orders a radically different construction approach of preliminary design, prefabrication and fast site assembly. Design and fabrication errors can be costly and difficult to correct on site. Quality control, promotion and education programs are essential for acquiring the confidence of contractors and building trust.

"*The contractor ... shies away from the steel house. The important difference between building with wood and steel is that nothing can be left to the discretion of the carpenter. ...Unless all details are worked out precisely on the drawing board, the overhead on a steel house can be ruinous to the contractor.*" Mc Coy, Case Study Houses.

Developers

Structural steel is an unfamiliar technology and the competitiveness of the residential market makes the developers cautious and conservative. To overcome their resistance, the manufacturers must provide a strong technical support and guarantees for their products.

"*The contractor/developer is not a trendsetter but a follower of trends. The steel industry has to offer the tools, something fully developed and ready for immediate use.*" Statement by the Dutch contractor WILMA at the 1995 IISI conference on Steel in Housing.

Steel Industry

Although, steel mills and manufacturers are supposedly getting the most benefits out of it, they very seldom considered steel houses as a serious market and often refused to collaborate except for a few exceptions shown in Appendix A, section 6.2.

Steel in housing requires specific solutions and the full collaboration of the steel industry. To work towards this objective, steel manufacturers must develop products, programs and services adapted to residential construction.

"Attempts of the steel company to design houses have been disappointing. Rather than take advantage of the steel principle, they pattern their work on wood." Esther Mc Coy, Case Study Houses.

Authorities

The application of steel to housing needs clear and simple rules accessible by all and requires a revision of National and Regional Building codes.

."..it became apparent that strong resistance from the Building Codes and labor organizations nullified whatever savings he had designed into the structure." Esther Mc Coy, about a Quincy Jones house, in Case Study Houses.

Financing institutions

Steel houses retain their value over time despite their unconventional and experimental aspect. The promotion of the technology to the financing institution and insurance companies is essential for a wider acceptance of the technology.

"Public Survey in 1936: After the Crystal house, 35 percent of the public would like to have a modern steel house, only one finance company is willing to mortgage it." Neil Jackson. The Modern Steel House-p.35

Barrier #2: The production of steel house requires a design-built approach.

Many designers of steel houses had difficulties communicating their ideas to the contractors because of the gap between concept and implementation. In her analysis of the Californian Case Study House Program, Esther Mc Coy summarizes again quite well the situation:

"(These) houses will remain individual performances until the architect can convince the contractor. The conception of an architect must be worked out by other hands and other minds than his own...Consequently, the changes in style in architecture must keep pace with the technical progress of the crafts."

Because of this communication gap and the reluctance of contractors for experiments and prototypes, many architects and designers found the design-build approach easier and more economical. Many notorious examples are shown in Appendix A, 6.3. These architects / builders were true pioneers acting against the mainstream and the lack of support from the steel industry. They were also following the logical path of steel towards a design-build approach that has become the norm for the metal building system industry.

Performances

Reason #3: Steel houses perform equally or better than other types of construction.

The ultimate goal of a house is user satisfaction. The spatial, thermal, integrity, air quality, acoustical and visual performance criteria described in Chapter 3 are measures of the adequacy of a house to meet physiological needs. On each of these criteria, the performance of steel houses is similar or better than any other types of construction.

1. Spatial

Mandate: The house must provide spaces to support individual and group activities.

A steel house can provide the same space as any traditional construction and the interior can be identical in such a way that it is impossible for the user to perceive the difference.
(See Appendix A, 3.3.)

Furthermore, the freedom from internal bearing walls and inherent flexibility of steel houses give them a superiority in space performance, for the steel house can have an open or unfinished layout adaptable to actual and future needs of the users. (See Appendix A, 2.4.)

2. Thermal

Mandate: The house must provide thermal comfort.

A steel house has the same potential for thermal comfort as a traditional house. Furthermore, a structural steel house can be wrapped in insulation panels and have a higher thermal performance level than a house with bearing external walls. (See Appendix A, 4.2.)

A steel structure allows the use of concrete floors, which bring additional thermal mass, damp the reaction to temperature changes, and increase the overall energy efficiency. A concrete floor can incorporate a radiant heat system that gives a higher heating standard and together with an appropriate window design, can form an efficient passive solar heating system. (See Appendix A, 4.3.)

3. Building Integrity

Mandate: The house must withstand external and internal forces and stresses over time.

Steel is a strong and stable material. (See Appendix A, 3.1.) Its performance over time is superior to any other construction material. A properly designed steel house will keep its integrity, will not crack, shrink or swell, will resist indefinitely to rot and insects. It is non-combustible and it will withstand earthquakes, winds and the overall wear resulting from the use of the building.

4. Air quality

Mandate: The house must provide air quality and prevent pollution emanating from building material.

Steel is a "clean air" building material. It does not release any toxic or gas from glue, organic compounds, or a previous chemical treatment. Steel can be protected with a low-toxicity, environmental friendly water-based paint. A steel house has the highest air quality standard of any other type of construction.

5. Acoustical

Mandate: The house must provide acoustical privacy both from inside and outside noises.

A steel house has the same potential for acoustical performance as a traditional house. Although, an open-plan layout offers less privacy than a layout with closed rooms, a steel house may, if required, have sound insulated rooms. Furthermore, outside walls, made free of structural elements, are more soundproof. Concrete floors, if installed, offer a superior acoustic performance over wood floors. Overall, steel houses match or exceed the acoustical performance of traditional wood framed houses.

6. Visual

Mandate: The house must provide adequate lighting.

The walls of a steel house are free of structural constraints (See Appendix A, 3.6.) Therefore, the location and size of openings in the envelope can be optimized in function of requirements of natural lighting requirements and solar energy (See Appendix A, 4.3.) A steel house provides a much higher lighting performance than any other construction method.

System Integration

Reason #4: Steel houses have a high level of integration between their elements.

As explained in Chapter 2, a steel house offers the possibility of much greater integration than a traditional wood construction.

1. The steel structure offers the opportunity of a better integration and optimization of the structural elements.
2. A steel house may use curtain walls, which usually include at once insulation, vapor barrier, electrical conduits, external siding, windows, and internal finishing.
3. The use of concrete floor with passive solar energy system or a radiant heat system increases the integration between the structural function of the concrete and its thermal mass properties.

Conclusions

In conclusion, the analysis of structural steel houses built during this century reveals that the technique is economically feasible and cost-effective because it promotes the conservation of resources. Structural steel in housing offers many advantages such as: strength, stability, durability, recyclability and lightness of material, spatial flexibility and adaptability, productivity, and fast assembly. The analysis also indicates that steel houses have similar or higher performances than other construction systems and offer a high level of integration. It shows also that, once they have made the step, the users enjoy them.

However, a wider acceptance of steel houses would require filling the communication gap between building professionals by promotional and educational programs. Steel houses require planning and system building methods that lead logically to a *Design-Build-Finance* approach where a single company designs, manufactures, sells, finances, installs, and guarantees the building.

Most examples used in this chapter refer to projects done many years ago. The remarkable development of steel and building technologies in recent years is an optimistic sign that the advantages and performance of steel houses will continue to prevail in the future.

CHAPTER 4 – A STEEL HOUSE IN SURREY, B.C.

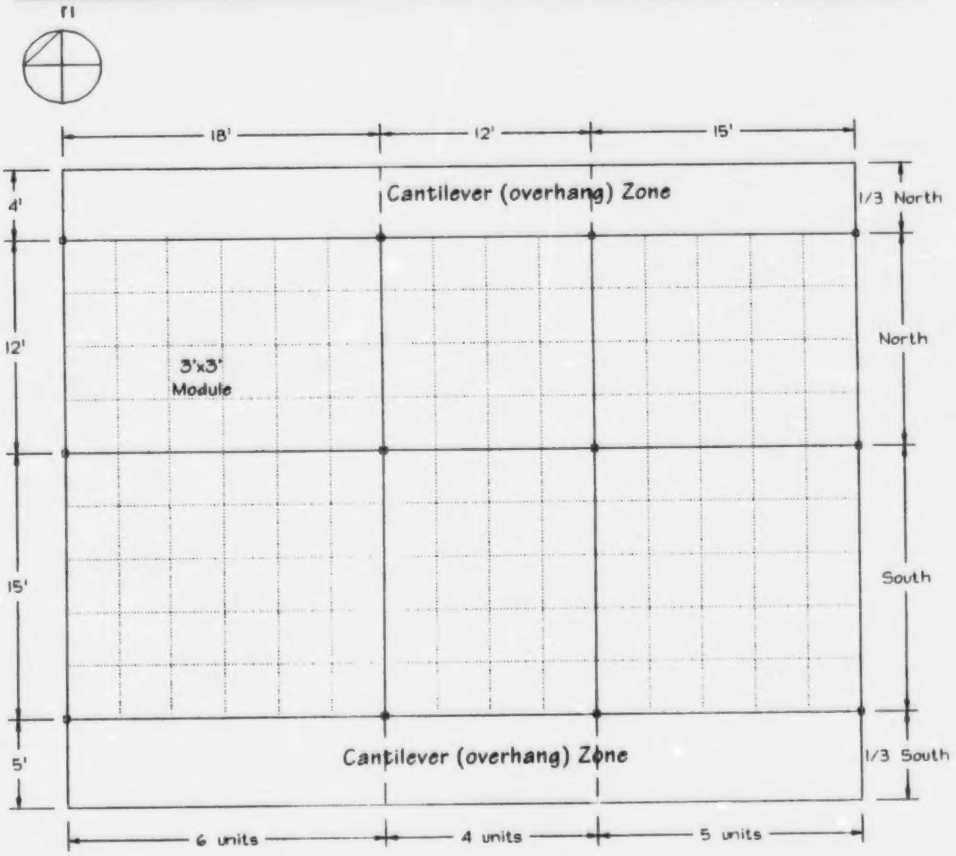
Introduction

Iron One, a steel house in Surrey, B.C, was built in 1991. The principles that governed the design of the house and the choice of a structural steel system were based on architectural, engineering, environmental, and economical decisions.

Design background

Modules: The design follows a 3'x3'x3' module (approx. 1x1x1 m). (see Figure 8). In the East-West direction, the plan has three zones of varying width. (6-4-5 units). The West row is the largest and is designed to accommodate the living rooms on the middle floor and an exercise studio on the lower floor. The smaller central row is designed for circulation space and rooms in which little activity occurs (dining room and master bedroom). The East row accommodates the rooms with the greatest level of activity such as the playroom, the kitchen,

Figure 8: Steel house in Surrey, modules and dimensions



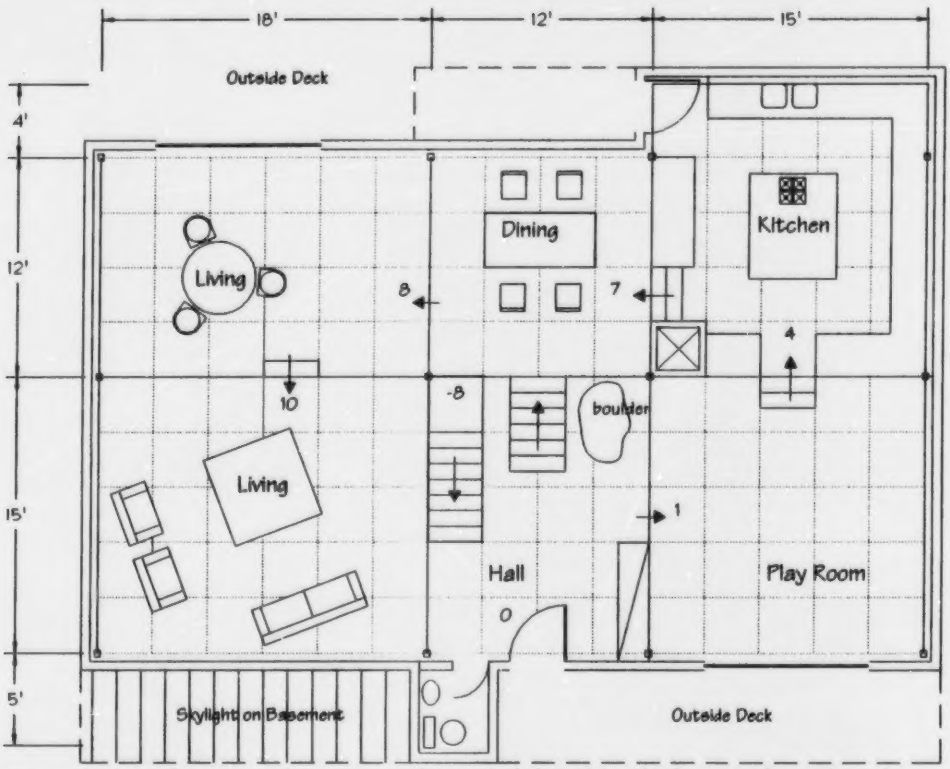
the children's rooms, and the master bathroom. In the North-South direction, the plan is divided in 2 zones of varying depth. The North zone, which receives less daylight, is shallower. These subdivisions create 6 main internal zones of different sizes defined by the location of the columns. In addition, there are two overhang zones North and south that create a transition from inside to outside.

The 3-feet module applies also to the elevation of the house as five stair rises correspond to one module. All floor levels are based on the number of steps above ground as indicated in the number shown in the plans in Figure 9 and 10. The design of the exterior wall and windows complies to the same module as the stairs, giving unity to the building and allowing the floors to follow the pattern of an ascending spiral

Program: The house is designed for a family of three but could accommodate more. At the ground level are the main living activities and at the upper level are two bedrooms and a guest room. (See Figure 9 & 10). At the lower level, the house contains a fitness studio.

Layout: The floor plans are open and flexible with few internal walls and wide span floors.

Figure 9: Main floor plan



The arrangement of rooms makes an ascending spiral that gives the house a dynamic and modern aspect. The interior spaces are delimited by varying floor levels and ceiling heights rather than by walls.

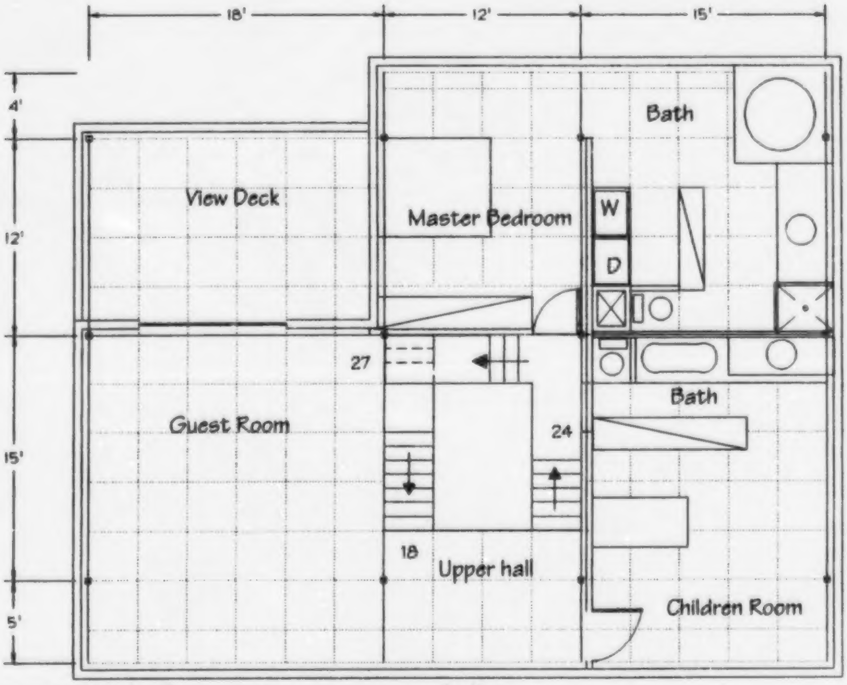
Exposed frame: The structural steel is exposed inside the house to create a sense of three-dimensional composition and simplicity.

Stairs: Steel stairs connect the various levels along the spiral. These stairs face south to act as a passive solar energy system. On the main floor, a large boulder provides additional thermal mass for temperature regulation and creates a contrast to the lightness of the steel structure.

Site: Large glass walls provide a view of the ocean located nearby and of the surrounding trees and gardens.

Floor: The floors are made of polished concrete on steel decks for maximal simplicity. The mass of concrete makes the rooms fresh in the summer. In the winter, a radiant heat system, incorporated in the floor creates a warm, cozy feeling.

Figure 10 : Upper floor plan.



Roof: The roof is flat for efficiency and simplicity and to gain maximum height while complying with local height restrictions.

Exterior spaces: The house has three exterior patio decks above the ground that are attached to the house and are built with the same structural steel as the rest of the building.

Technical

Structural: Structural steel supports the main loads while steel stud frames transmit the secondary wind loads to the primary frame. The complexity of the design and the large spans were the deciding factors for choosing steel. A preliminary study, provided by Mc Millan Bloedel, indicated that the use of *Parallam* beams would have made the project more expensive.

Other materials: The main construction materials, other than steel, are concrete and glass, there is very little wood. The house contains therefore mostly non-combustible material.

Seismic: The house is built in one of the highest seismic zone in Canada (Zone 4).

Environment and energy

Energy: Large south-facing windows and the thermal mass of the concrete floors form a passive solar energy system that reduces energy consumption. The concrete floors contain a hot water radiant heat system with fifteen loops individually controllable to improve the comfort and energy efficiency.

Footprint: The foundations stand partially on pier footings to minimize the footprint and preserve the roots of nearby trees.

Economical

Low budget: The target was to stay below the cost of traditional wood-frame construction on a dollar per square meter basis.

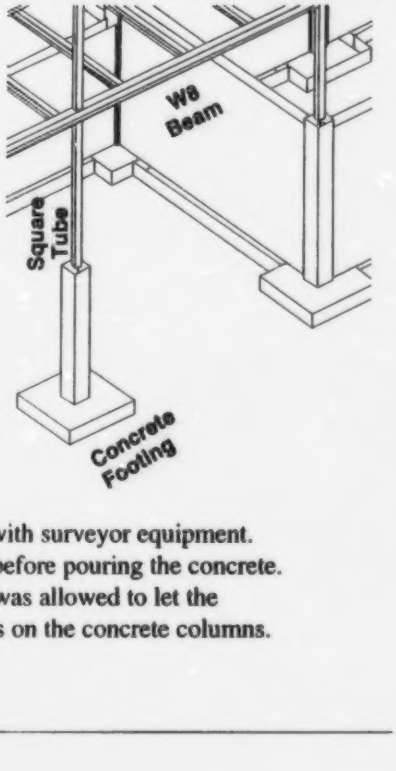
Fast occupancy: The need for rapid occupancy commanded a fast construction system.

Description of the construction system

The construction method is an application of Industrial / Commercial (IC) building methods to residential construction. The main components of the basic building are concrete foundations, structural steel, concrete floors on steel decks, flat roofs with a rubber membrane, and steel studs walls (see Figure 15 & 16). The house was designed with a three dimensional CAD system and most elements were prefabricated and brought to the site for assembly. The construction involved very few of the traditional house building trades. Most contractors came from the IC construction sector and had no experience in dealing with residential construction.

Obtaining a building permit did not present additional difficulties, except that the Building Code required design and review of the structural part by a Professional Engineer.

Figure 11: Column and foundation details



The following is a brief description of the building system, as well as a critical review of the problems encountered, and suggestions for improvement.

Foundations

The foundations consist of 28 MPa concrete footings 1m x 1m x 0.2m (thick) (40"x40"x8") that are located under each steel column. The site has good soil bearing properties.

The footings are connected by 8" thick concrete walls, which form a basement. On the southeast side, the foundation wall is interrupted and the structure stands on pier footings to preserve the roots of nearby arbutus trees. (See Figure 11)

The construction of the foundation took four steps:

1. Footing forms installation.
2. Footings casting.
3. Installation of the piers and walls forms. The position of the forms and the steel column bolts were accurately located with surveyor equipment. The bolts for the steel columns were secured with a template before pouring the concrete.
4. Casting of the concrete walls and columns. Some extra-time was allowed to let the concrete cure, because the structure imposes heavy point loads on the concrete columns.

Critical review

The construction and positioning of the plywood forms for the column supports required extra care and cost more than in traditional construction. The use of off-the-shelf forms, such as Sonotube, could reduce these costs. The column bolts could be installed by drilling in the concrete and installing chemical (epoxy-based) anchors. This method would reduce the risk of displacement and errors during the pouring of the concrete.

Structure

The main structure is a post and beam structural steel system. Although the structure has different spans and loads, it uses only five different types of standard profiles for simplification and cost effectiveness. (See Figure 12 & 13.) A local steel workshop pre-fabricated the elements and a crew of two steel erectors assembled the structure on site with a crane. Neither the steel manufacturer nor the erectors had previous experience in housing.

The steel structure contains the following elements:

- Twelve HSS 101x101x6 (HSS 4x4 x ¼) square columns with lengths varying from 3 m (10') to 9.15 m (30').
- Twenty-one W200x27 (W8x18) main beams. The beams form a cantilever on 1/3 of their length to reduce the deflection and the maximum moment. The distances between beams vary from 3.6 m (12') to 5.5 m (18').
- Thirty W150x18 (W6x12) floor joists spanning between the main beams and located at 1.22 m (4') o/c.
- Fifteen C200x17 (C8x11.5) floor joists acting as floor edges.
- Seventeen C150x2 (C6x8.2) roof joists located at 1.22 m (4') O/C, sitting on top of the beams.

The lateral stability is provided by a system composed of

- one "K" and two "A" bracing made with HSS 101x101x6 (HSS 4x4x¼)
- Three "A" bracing made with HSS 76x76x4.8 (HSS 3x3x3/16) stabilizing the roof
- Cross bracing made with 5/8" round bars in the East and West walls.
- The stairs also braces the structure as it is made with the same heavy steel elements as the main structure. (Figure 13

Figure 12 : Structural model

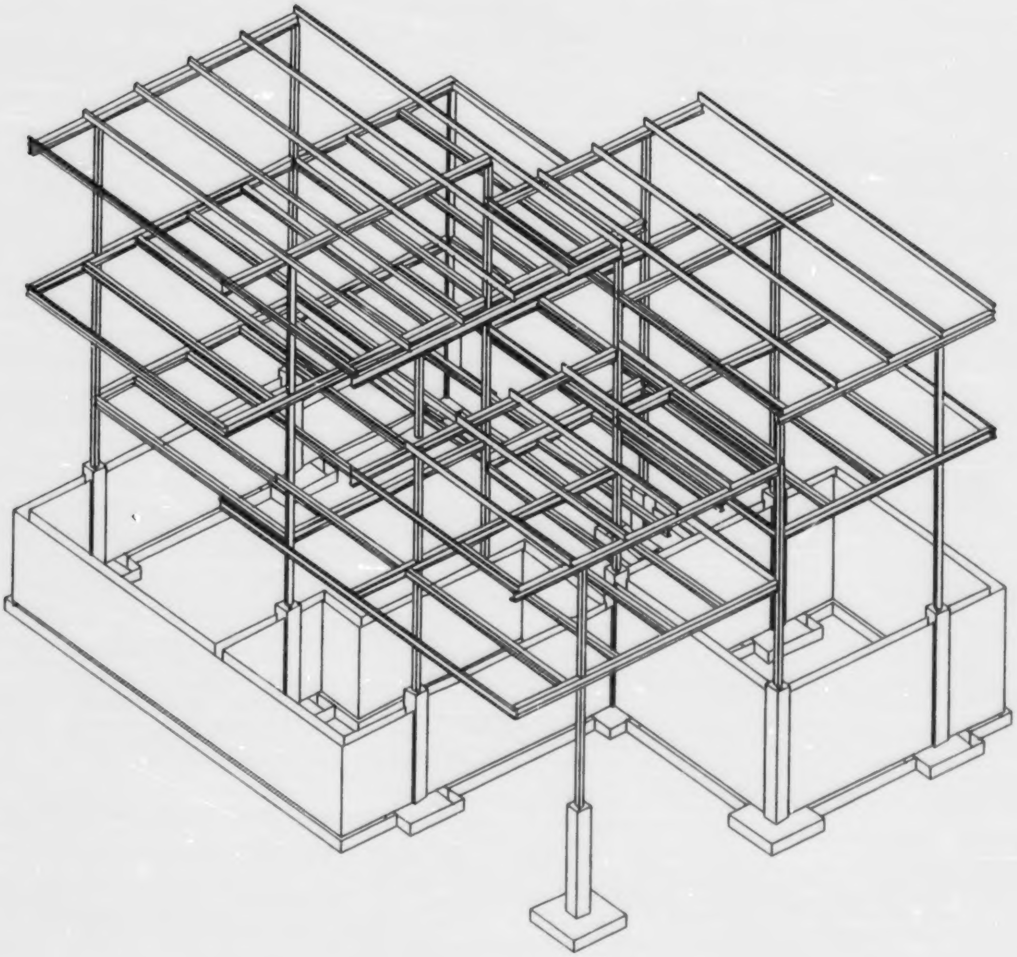
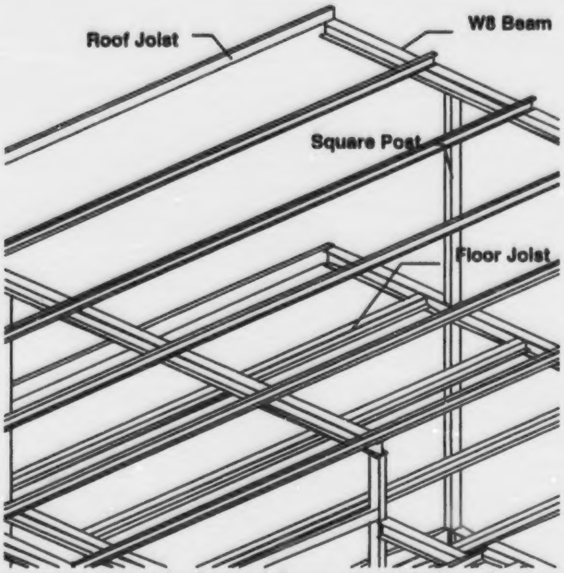


Table 8: Design loads	
Occupancy Live Load – kPa	1.90
Ground Snow load – kPa	2.2
Rain in Snow – kPa	0.3
Hourly Wind Pressures 1/10 – kPa	0.46
Hourly Wind Pressures 1/30 – kPa	0.58
Hourly Wind Pressures 1/100 – kPa	0.72
Acceleration-related seismic Zone - Za	4
Velocity-related seismic Zone – Zv	4
Zonal Velocity ratio - v	0.2

The connections between columns, beams and joists are made as simple as possible with clip connectors and two bolts per connection. (See Figure 14)

The structure was calculated by the limit state design method with the design load factors of Table 8. The models took the conservative assumption that the walls do not carry any vertical loads and only transmit wind loads to the structure.

Figure 13: Beams and joists assembly details



In comparison to standard wood frame construction, the sequence for the construction of a steel house introduces additional steps in design and prefabrication. The sequence of construction was:

1. Pre-engineering, design made with the help of a 3-D CAD model (see Figure 11), and calculation of the structure.
2. Detailed shop drawings, prepared by the steel fabricator and done in 7 days.
3. Shop fabrication, done in 5 days.

Erection done by a crew of two steelworkers, and a crane mounted on the flat bed truck that transported the pre-fabricated steel to the site. The complete structure was erected in one single day. The next day the structure was adjusted, bolted and "snug-tightened" (CSA requires that the bolts are tightened to ensure that the parts of the joint are brought to full contact with each other)

Table 9 summarizes the cost and time data for the structural steel system.

Critical Review

Reducing the number of structural profiles brought simplification but increased the total weight and consequently the cost of the structure, which was priced on a dollar per tonne basis. This solution was, however, the only viable one for a single, isolated, small project. The cost of steel waste would have been otherwise too prohibitive. The use of lighter elements, now available in the USA and the planning over many projects could have somewhat reduced the weight of the structure.

Although the stairs participate with the lateral bracing system, the structural calculation did not include it. A more integrated approach could improve the overall structural efficiency and create further cost reductions.

Floor

Once installed, a structure offers the immediate benefit of ease and speed of installing floors and roofs. The floor consists of a composite slab of concrete on top of a steel deck made with Gauge 22 zinc coated steel, the deck has 38mm (1.5") valleys with embossed indentations – or "keys" that create a strong cohesion between the deck and the concrete.

A commercial sheet metal contractor supplied and installed the deck. The company had no previous experience in residential construction.

The concrete slab thickness is 50 mm (2"), not including the valleys. The installation of the deck was done according to the following steps:

Table 9: Steel statistics from the steel house in Surrey.

Weight (Metric Tonnes)	
Main structure, including bracing	11.25 t
Accessories: Stairs, Outside Deck	3 t
Timing (days)	
Engineering design	10 d
Detailed design	7 d
Shop Fabrication	5 d
Erection	2 d
Cost CAD$ 1991	
Structure	$25,000
Accessories (Stairs, rails, Deck)	$ 6,800
Area and ratio.	
Total Area m2 including outside deck	400 m2
Structure Weight kg per m2	28 kg/m2
Structure Cost $ /m2	62.50 $/m2

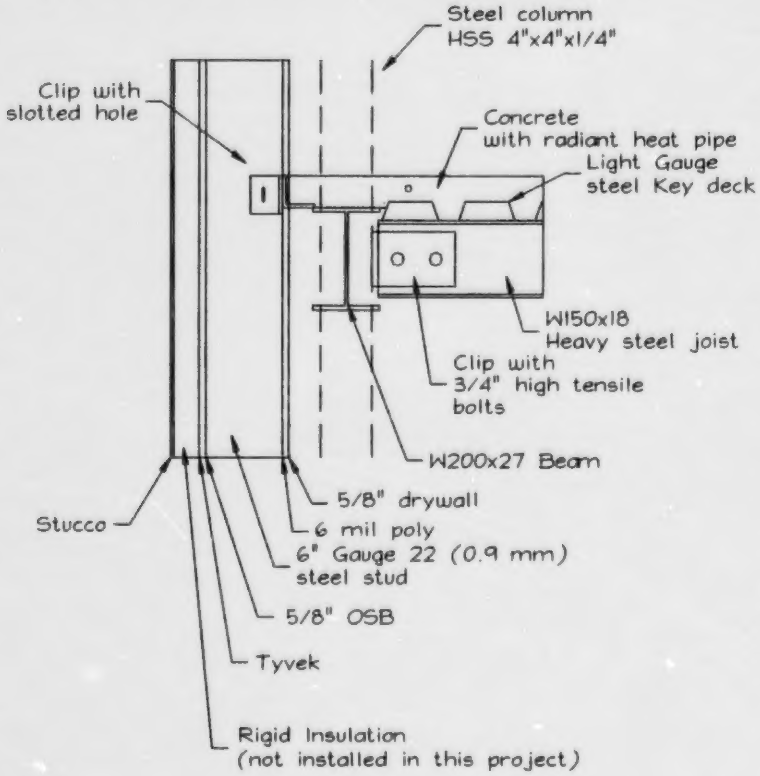
1. The steel deck elements arrived on site pre-cut at exact length. Steel decks are lightweight (8 kg/m2 - 1.67 lb. /ft2) and can be handled and installed by a crew of two workers. The deck spans 1.22 m (4") between joists and, once laid on the structure, becomes an immediate working place. This job took one day to complete, including the roof deck (see below.)
2. The deck was crimped together and tack-welded to the structure the next day. (One day)
3. A 6x6 steel mesh was laid on the deck to reduce cracks in the concrete and to provide points of attachment for the radiant heat pipes.
4. Loops of 16mm polyethylene pipes were laid on the mesh and attached thereto. The distance between pipes varies between 300 mm (12") and 150 mm (6"). This operation took 2 days.
5. Together with the angles welded on the perimeter beams, the deck formed a self-supporting and permanent concrete shoring system. A 28 MPa concrete grout was poured on the deck, polished, and sprayed with a curing agent. The whole operation took a single day.

Critical Review

The concrete floor and steel frame form a composite section and act together to resist the loads, whenever the moments are positive. However, the calculation did not take into account the composite section but only the steel structure. The reasons were that the effective thickness of the concrete slab is below standard (50 mm instead of 65 mm), and because, due to the relatively shallow section, the deflections during the installation of the concrete governed the design.

The slenderness of the concrete slab combined with the incorporation of ½" plastic pipes make it difficult to avoid concrete cracking.

Figure 14: Floors and walls connection details



Roof

The roof uses the same type of steel beam and decks than the floors for design simplification and cost reduction. The roof deck was installed the same day as the floor. The roof covering was installed after the completion of the wall framing. In the mean time, the bare deck offered temporary weather protection for the crew working inside the house.

The main application of EPDM roofing is in large warehouse construction. The contractor, which has no previous experience in residential construction, successfully overcame the challenge of applying the technology to a smaller job.

1. R30 urethane rigid insulation was laid on the deck. (½ day).
2. Tapered polystyrene blocks were added to create a slight slope and avoid water stagnation.
3. EPDM membrane was laid on top of the insulation, glued together, and attached to the roof sides.
4. Gravel ballast was added on top op the membrane to prevent the uplifting of the membrane. The ballast has the additional effect of protecting the membrane against the solar UV rays and reducing heat gain in the summer. EPDM and ballast were installed in one day.

Critical Review

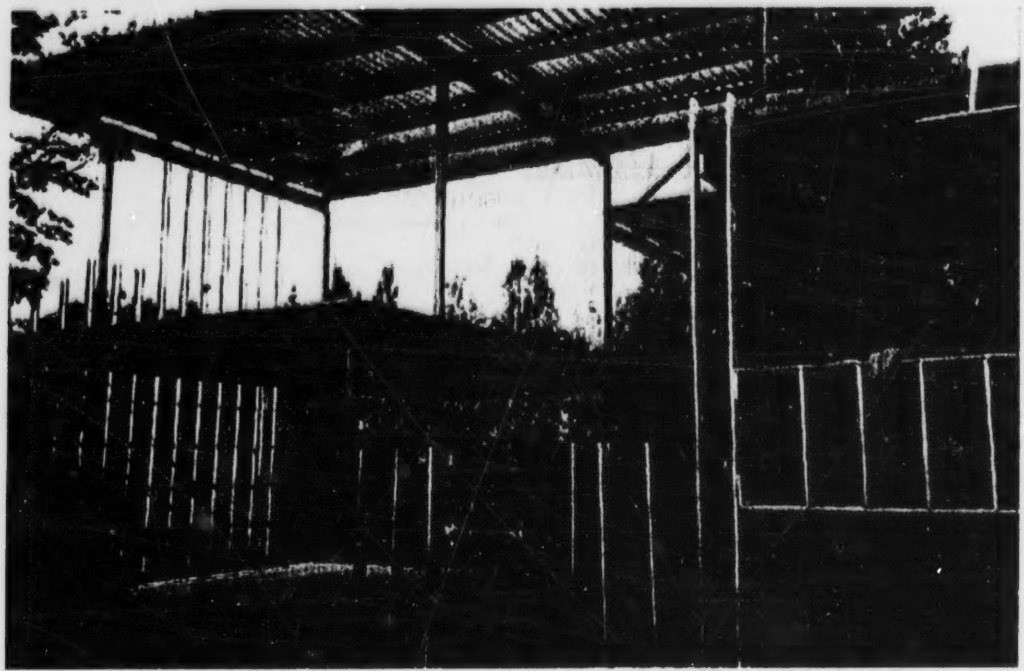
The gravel ballast adds an unnecessary load to the structure. Attaching the membrane directly to the rigid insulation could eliminate the need for ballast.

Walls

The walls are made with steel studs, 5/8" OSB, Tyvek building paper and ¼" Hardy board.

The studs are designed to support only wind loads and to act as a curtain wall, for the structure supports all the other loads. All the studs have the same section: 152 mm (6 inches) C channel with a thickness of 0.9 mm (0.036 inches or Gauge 22.)

Figure 15: Steel house in B.C. during construction.



A computer program calculated the exact size of each stud and the manufacturer used the data to cut the elements at length. As a result construction waste and assembly costs were minimized. Both the manufacturer and the contractor had no previous experience in residential construction. The main use of steel studs was, - and still is- to support drywall and curtain walls in commercial buildings. The house is now displayed on the cover page of the stud manufacturer catalog.

Steel studs are lightweight, weighing approximately 1.80 kg/m [1.21 lbs./ft]

The assembly of the wall followed the sequence below:

1. On the ground, a crew of two assembled the wall frames with studs at 16" o/c and lifted them to the structure.
2. A bolt attached the steel stud frames to the structure via a slotted hole that allowed for differential vertical movement.
3. A 5/8" OSB board was screwed to the exterior of the frame and wrapped in Tyvek building paper. The exterior wall was finished with cementitious panels (Hardy board) and two coats of stucco.

The structure does not penetrate the walls for limiting thermal bridges.

Critical Review

The studs in the wall create thermal bridges that reduce the overall insulation efficiency of the envelope. Recent study indicates that adding rigid insulation panel on the exterior side of the studs substantially increases the insulation efficiency of the wall.

Windows

The window area represents approximately 50 percent of the total wall area. This high percentage was made possible by the use of structural steel and curtain walls.

The windows are made with thermally broken aluminum frame and double-pane glass. Wood is inserted between the aluminum window frames and the galvanized steel frame to avoid electrolytic corrosion and reduce thermal bridges.

Both the manufacturer and the installer were from the commercial sector.

Table 10: House dimensions

Item	Amount	Unit
House Internal Area	351	m2
Outside decks Area	49	m2
Total area including outside decks	400	m2
Building Maximum height	10	m
Building Length	13.70	m
Building Width	11	m
Footprint	138	m2

The windows were installed on the external frame after the installation of the OSB boards, the Tyvek paper, and Hardy boards. Complete installation took 2 days.

Critical Review

Recent developments in glass technology have considerably improved the energy efficiency of windows system. Today, there is a wide availability of high-performance windows, which feature Low-E coatings, inert gas fills and insulated frame and edge components.

Table 10 presents the main dimension of the house and Table 11 shows the quantity of material that was used to build it. As shown in Table10, the house has a compact size and a small footprint relative to the livable area.

Table 12 presents the costs in CAD$ (1991) for the total construction subdivided in three main categories.

- Primary elements, which include all the basic construction works and elements of the building such as site preparation, foundations, steel structure and stairs, floor and roof deck, concrete floor, roofing, steel studs wall frame, wall boards, insulation and windows. This category contains all the elements specific to a steel house and therefore it can be used for evaluating the costs of steel versus any other construction technique. The total cost was $113,200, which represented 46 percent of the total cost. The cost per floor area including the outside deck area was $283 / m2 ($26/ft2), including decks. The deck is included in the total area because it was made with the same steel and concrete elements as the rest of the house. Cost excluding the deck was $322/m2 ($30/ft2)
- Services, which include electrical, heating, plumbing, and all the fixtures for the kitchen and the bathrooms. The costs of electrical and plumbing were similar to a traditional construction. The cost of radiant heating system was low because of the ease of installing radiant heat pipes on a steel deck. The cost for kitchen and bathroom fixtures may vary according to the taste and needs of the users and cannot be used for comparison.

- Finishing, which include the exterior stucco, drywall, painting, interior finish, doors, trimming, the exterior deck floor, and the cost supervision, administration and permit. These costs are largely independent of the type of construction and cannot be used for comparison purpose.

The additional columns of the table represent the following:

% sub, which is the percentage of the subtotal of each category, shows that the steel structure is approximately one fifth of the total cost of the basic building. It is worth noting that the cost of structural steel is lower than the cost of windows.

% tot is the percentage to the total building cost, noting that the type of finishing and quality of accessories may significantly affect the total building costs.

The total cost was $594/m2 ($55/ft2 including outside decks) – or $ 676/ m2 ($63 /ft2 excluding outside decks). It was similar, if not lower, to the cost of a traditional wood frame construction house, which, in B.C. at the same period , were between $700/m2 and $1075/m2 ($65 and $100 per square foot).

Table 11: Material Quantity

Item	Amount	Unit
Foundation Volume	40	m3 @ 28 MPa
Steel main structure	11.25	tonnes
Steel secondary (stair & outside deck)	3	tonnes
Floor Deck Area	258	m2
Floor deck steel weight	2.1	tonnes
Steel studs Steel Weight	1,400	linear m
Floor deck steel weight	1.9	tonnes
Roof Deck Area	124	m2
Roof deck steel weight	1	tonnes
Concrete Floor Area	315	m2
Concrete Floor Volume	21	m3
Floor on Grade	123	m2
Concrete on grade	12.5	m3
External Wall Area	180	m2
Windows Area	179	m2
Total Concrete Volume	73.50	m3
Total Steel weight, structure, outside patio, stairs, floor and roof decks, studs	19.25	tonnes
Steel weight / total area	48.75	kg /m2

Table 12 presents a flow chart of the primary phase of the construction project. It shows that the construction of a steel house can be fast-tracked. The fabrication of the steel structure occurs during the building of the foundations. In the following three weeks, the building is assembled, closed, and ready for the finishing phase. The building base can be built in 28 days.

Conclusions

Iron One, a steel house in Surrey, B.C. is a demonstration that structural steel can be successfully applied in Canada. The project provided valuable experience on the benefits of the technology as well as the opportunities for improvement.

The cost was similar to traditional wood frame construction, despite the complexity of the layout and the experimental nature of the project. The construction went fast and employed mainly contractors from the IC sector who had no previous experience in residential construction.

The house has a light, open feeling and offers high satisfaction to the users. The energy consumption is comparable to other houses of the same size. An efficient radiant heat system combined with passive solar energy offset the losses through large windows and steel studs in the wall. New windows and curtain walls technology could, however, significantly increase the energy efficiency of the house.

Steel gives the house strength, quality and stability. The walls are straight, stay true, and do not crack nor move. The house did not require any post-construction repairs and is virtually maintenance-free.

Overall, the project demonstrated that structural steel in housing is economically feasible, has performances superior to traditional construction method and provides great living space.

Table 12. Construction Timing

			Wk 1	Wk 2	Wk 3	Wk 4	Wk 5	Wk 6	Wk 7	Wk 8	Wk 9	Wk 10
		Days	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50
Prep.	Site prepar.	2	□□■■□	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□
	Digging	1	□□□□■	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□
Found.	Footings	3	□□□□□	■■■□□	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□
	Wall Foundation	7	□□□□□	□□□■■	■■■■■	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□
	Water proofing	1	□□□□□	□□□□□	□□□□□	□□□□□	■□□□□	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□
	Curing	7	□□□□□	□□□□□	□□□□□	■■■■■	■■□□□	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□
Steel	Engineering	10	■■■■■	■■■■■	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□
	Detailed design	7	□□□□□	□□□□□	■■■■■	■■□□□	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□
	Shop Fabric.	5	□□□□□	□□□□□	□□□□□	□□■■■	■■□□□	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□
	Erection	2	□□□□□	□□□□□	□□□□□	□□□□□	□□■■□	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□
	Final adjustment	1	□□□□□	□□□□□	□□□□□	□□□□□	□□□□■	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□
Deck	Laying	1	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□	■□□□□	□□□□□	□□□□□	□□□□□	□□□□□
	Welding	1	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□	□■□□□	□□□□□	□□□□□	□□□□□	□□□□□
Floor	Preparation	2	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□	□□■■□	□□□□□	□□□□□	□□□□□	□□□□□
	Heating pipes	1	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□	□□□□■	□□□□□	□□□□□	□□□□□	□□□□□
	Concrete	1	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□	■□□□□	□□□□□	□□□□□	□□□□□
Roof	Insulation	1	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□	□□■□□	□□□□□	□□□□□	□□□□□
	EPDM	1	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□	□□■□□	□□□□□	□□□□□	□□□□□
Walls	Framing	5	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□	□□■■■	■■□□□	□□□□□	□□□□□	□□□□□
	Boarding	5	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□	□□■■■	■■□□□	□□□□□	□□□□□
	Exterior Finish	10	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□	■■■■■	■■■■■
Windows	Installation	2	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□	□□■■□	□□□□□	□□□□□
	Caulking	1	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□	□□□□□	□□□□■	□□□□□	□□□□□

Table 13: Steel house in Surrey, building costs

Building base	Cost $	% sub	% tot	$/ft2	$/m2	Comments
Site preparation	$3,500	3%	1%	$0.82	$8.75	Excavation and back filling
Foundation	$11,600	10%	5%	$2.70	$29.00	Forms and concrete
Steel Structure	$25,000	22%	12%	$5.82	$62.50	Fabrication and erection
Steel Deck	$5,800	5%	2%	$1.35	$14.50	Material and Installation (wall & roof)
Floor Concrete	$5,800	5%	2%	$1.35	$14.50	Concrete, polishing, labor.
Steel Stairs	$6,800	6%	1%	$1.58	$17.00	Material & erection incl. handrails and outside deck support
Steel Studs	$8,100	7%	3%	$1.89	$20.25	Material and installation.
Roof	$4,500	4%	2%	$1.05	$11.25	EPDM, gravel and installation
Walls	$1,600	1%	1%	$0.37	$4.00	OSB Board outside
Windows	$26,400	23%	11%	$6.15	$66.00	Material and installation
Insulation	$8,100	7%	3%	$1.89	$20.25	Material and installation
Supervision	$6,000	5%	3%	$1.40	$15.00	General Contractor and supervision.
Total Building base	**$113,200**	**100%**	**48%**	**$26**	**$283**	

Services	Cost $	% Sub	%Tot	$/ft2	$/m2	
Electrical	$10,000	21%	4%	$2.33	$25.00	Material & installation: wiring, cable, phone, and equipment.
Heating	$10,900	22%	5%	$2.54	$27.25	Material & installation: Radiant Heat System.
Plumbing	$11,000	23%	5%	$2.56	$27.50	Material & installation: pipes and basic fixtures.
Kitchen, Bathrooms	$16,800	34%	6%	$3.91	$42.00	Kitchen and bathroom fixtures
Total services	**$48,700**	**100%**	**20%**	**$11**	**$121.75**	

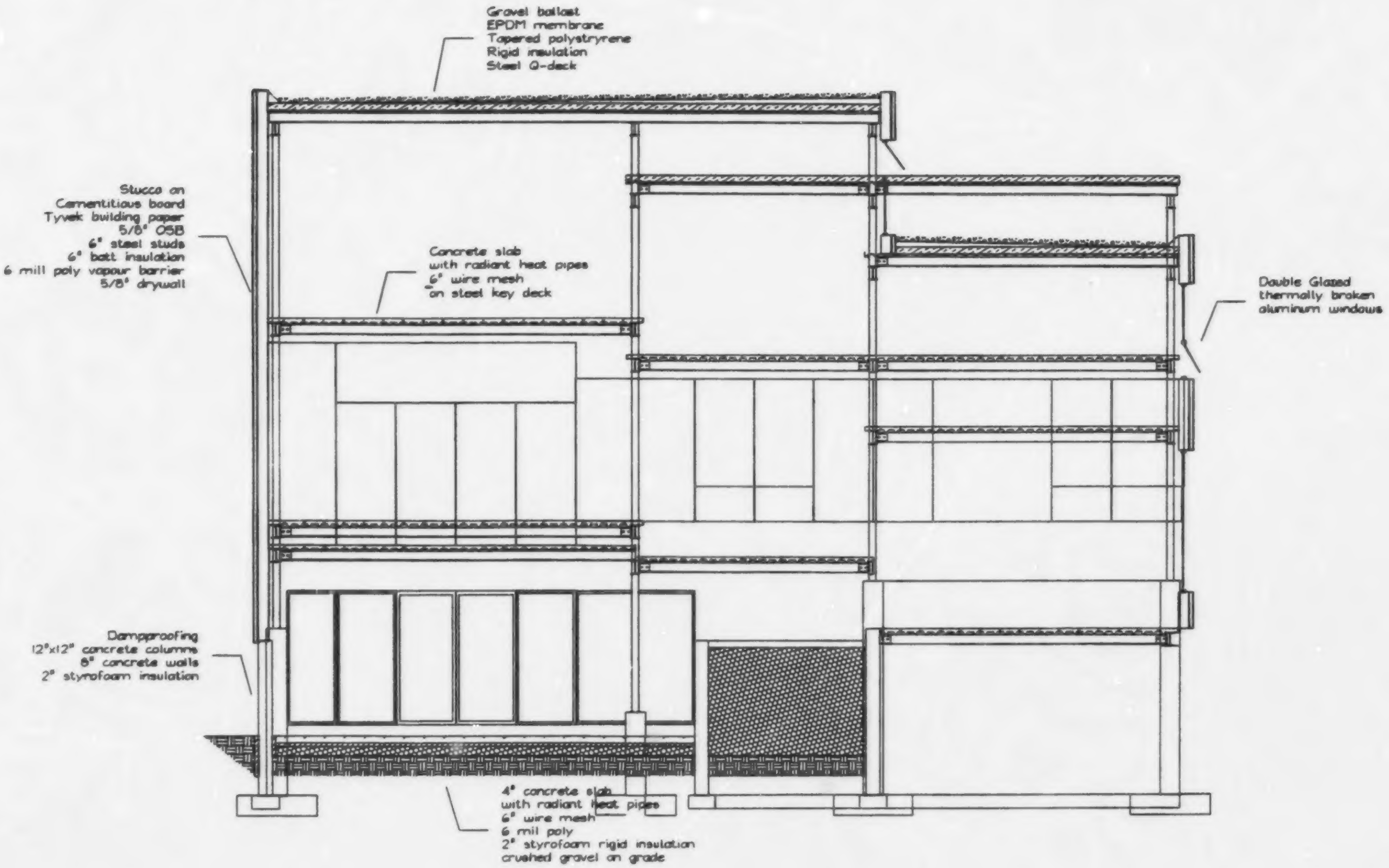
Finishing & General	Cost CAD$	% Sub	% tot	$/ft2	$/m2	
Stucco	$16,600	22%	7%	$3.87	$41.61	Tyvek, hardy board, stucco
Interior Finish.	$26,800	35%	11%	$6.24	$67.18	Material & installation: Drywall, painting, floor polishing, doors, and tiles.
Miscellaneous	$13,400	18%	6%	$3.12	$33.59	
Exterior deck	$2,200	3%	1%	$0.51	$5.51	Cedar wood decking on steel structure.
Supervision	$6,000	5%	3%	$1.40	$15.04	General contractor and supervision of finishing
Administration, Permit	$10,500	14%	4%	$2.45	$26.32	Architectural design, engineering, permitting, insurance, general administration.
Total Finishing	**$75,500**		**32%**	**$17.58**	**$189.26**	

Grand Total	**$237,400**					Total cost
Area ft2 excl. patio	3780			$63		Cost per ft2 excluding outside decks
Area m2 excl. patio	351				$676	Cost per m22 excluding outside decks
Area ft2 incl. patio	4300			$55		Cost per ft2 including outside decks
Area m2 incl. patio	400				$594	Cost per ft2 including outside decks

%sub: percent of category sub-total, %tot: percent of Grand total, $/ft2: Cost per square foot including exterior deck, $/m2: Cost per square meter including exterior deck.

Exterior decks are included in the cost because they use the same elements as the rest of the house.

Figure 14: Cross Section



CHAPTER 5 - INDUSTRY GROUPS AND PUBLICATIONS

There are many agencies and organizations in the world dealing with steel. The majority focus on industrial and commercial (IC) construction and consider structural steel in housing as a marginal, if not irrelevant, activity. Since a steel house may be considered an application of IC construction to housing, these organizations are an excellent source of information for techniques related to steel, steel construction, steel building systems, and components. These groups represent generally three sectors:

- Industries that produce and fabricate steel.
- Professionals that design steel structures and build with steel.
- Businesses that specialize in building systems.

This chapter provides a brief description of each of these organizations and Appendix C provides their addresses, their phone numbers, their web sites and their e-mail addresses, and where to find additional information about their programs and activities.

Production and fabrication

The following sections describe the main organizations in Canada and abroad that represents the interest of steel mills, steel fabricators, and steel construction companies.

CANADA

CISC

The Canadian Institute of Steel Construction (CISC) which is identified by this logo, represents in Canada the structural steel, open web steel joist and steel platework fabricating industries. The CISC promotes good design and safety, together with efficient and economical use of steel with the objective of expanding the construction markets for structural steel. The CISC publishes the *Handbook of Steel Construction,* which is a fundamental reference for everyone designing with steel. The manual contains structural steel design guidelines based on Canadian Standards. It deals with every aspects of steel construction, such as connections, bolts, welding, columns, beams, structural profiles and properties of steel. Other publications from the CISC include:

- *Limit States Design In Structural Steel,* which addresses the concept and practical application of limit states design procedures.
- *Hollow Structural Section Connections and Trusses*, which deals with design, fabrication and welding information on connections involving HSS members.
- *Standardized Shear Connections*, which lists the capacities of representative simple shear connections and the applicable span ranges for specific beams.
- *Design And Construction Of Composite Floor Systems*, which reviews steel-concrete composite floor systems comprised of deck-slabs, composite beams, girders, trusses, and stub-girders.
- *Fundamentals Of Structural Shop Drafting,* which contains over 200 drawings, illustrations and tables, a review of basic drafting principles, typical drafting methods, sample calculations and solved problems.

The CISC also publishes a design aid for single-storey and low-rise building containing practical examples and method for design and engineering the most common IC steel building.

For structural engineers and designers, the CISC proposes *Gravity Frame Design V4.0* a computer program that provides most of the functions for calculating a steel structure and the *Structural Section Tables* (SST) that contains the North American database of structural steel sections listed in the CISC Handbook of Steel Construction.

The CISC publishes also a quarterly magazine on steel construction, "*Advantage Steel*", which contains case studies of steel construction, mostly in the industrial, commercial and institutional sectors.

At the present time, the CISC is not often dealing with housing because the market is not developed. Steel houses are usually associated with steel studs rather than structural steel and therefore, they are considered the field of the CSSBI (See below) rather than the CISC. However, CISC representatives acknowledge that demonstrating of the cost-effectiveness and applicability of structural steel to the Canadian residential market could change the mainstream opinion that steel houses are made exclusively with steel studs.

CSSBI

The Canadian Sheet Steel Building Institute (CSSBI,) is the national association of companies involved with structural sheet steel and steel studs. In recent years, the CSSBI launched "Homesteel" which is a promotion to the use of light gauge galvanized steel framing (steel studs) in residential construction. The CSSBI produces a variety of publications: Industry Standards, design aids, technical notes, promotional brochures and special items. In collaboration with its US counterpart, the American Iron & Steel Institute (AISI,) the CSSBI publishes the "Low Rise Residential Construction Details" manual, which contains practical guidance on design, detailing and construction of the low-rise residential buildings that uses steel studs.

CSPA

The Canadian Steel Producers Association (CSPA) represents Canada's primary steel producers. Canadian steelmaking is a high value-added industry with sales of $11 billion, over $3 billion in exports and 33,400 employees. (See Chapter 7.) The CSPA has 15 members accounting for over 90 percent of Canadian steel and producing flat products (plate, hot and cold rolled sheet, coated sheet) and long products (bars, rods, rails, special and structural shapes) in a wide variety of sizes, coatings, chemical compositions and physical properties. CSPA members also own over 20 downstream production facilities - producing pipes and tubes, wire and wire products. Half of the Canadian steelmaking capacity is based on electric arc furnace technology (EAF).

The CSPA has also a research branch, known as the Canadian Steel Industry Research Association (CSIRA), which works in close relationships with the industry and a national network of government and university laboratories.

USA

AISI

The American Iron & Steel Institute (AISI) is the US association of furnaces, mills, steel suppliers, and producers. Its mission is to promote steel as the material of choice and enhance the competitiveness of the US steel industry. Traditionally, producers of light gauge cold-formed profiles are members of the AISI. Therefore, this organization is also actively promoting the use of steel studs in residential construction and it publishes many references and manuals on the subject. AISI is also behind the "*New Steel*" promotion program (see Chapter 1).

AISC

The American Institute of Steel Construction (AISC) is the US counterpart of CISC. It is a non-profit association representing and serving the fabricated structural steel industry in the U.S. Its purpose is to expand the use of fabricated structural steel through research and development, education, technical assistance, standardization and quality control. Traditionally, the members are structural steel designers, fabricators and contractors. The AISC publishes standards and guidelines such as the widely consulted "*AISC Manual or LFRD Manuals*", which is the US equivalent to the Canadian *Handbook of Steel Construction*. The AISC also publishes the monthly "*Modern Steel Construction*" magazine, which offers articles of general interest about steel technology.

SRI

The Steel Recycling Institute (SRI) is an industry association that promotes and sustains the recycling of all steel products through a wide-range of programs such as public awareness, promotion of educational material for schools, and creation of an online database of steel recycling locations. Steel is the first recycled material in North America. In 1996, the steel industry recycled 67 million tonnes of steel, which represents an overall recycling rate of 68.5 percent. The recycling rate depends on the steel-making process: the basic oxygen furnace process, which produces steel for packaging, car bodies, appliances and steel studs framing, uses about 28 percent recycled steel. The electric arc furnace process, which produces steel shapes such as railroad ties, structural steel and bridge spans, virtually uses 100 percent recycled steel.

The recycled steel comes from various sources shown in Table 14.

Table 14: Steel recycling rate in 1997.

Origin	Recycling Rate %	Quantity recycled	Tonnes steel recycled
Cans	60 %	20 billion cans	1.6 million
Appliances	75 %	46 million appliances	2.2 million
Automobiles	97.9 %	12 million cars	12 million
Steel from demolition sites	80 %	N/A	N/A
Rebar	20 %	N/A	N/A

Recycling steel reduces solid waste. Recycling steel from demolition debris is easy due to steel's magnetic properties. In average in the US, 45 percent of the construction landfills consist of wood debris. Steel accounts for less than 6 percent. In GVRD, 60 percent of the construction waste consists of wood debris and less than 1 percent is metal (GVRD statistics).

Recycling steel has other environmental benefits, besides reducing solid waste. The amount of steel recycled in a year saves the equivalent energy consumption of 18 million homes per year. Recycling saves other resources because every tonne of steel recycled saves 1.25 tonnes of iron ore, 0.635 tonnes of coal, and 54 kg of limestone.

The SRI is promoting steel as a sustainable material and it focuses on the principles of environmentally friendly construction, green building, life cycle assessment, and sustainability. The SRI is member of the *New Steel Alliance* (see Chapter 1), which promotes steel as a strong, modern, and sustainable material. It participates in the Sustainable Steel Conference on Steel in Green Building. The subject is: "*How steel can be creatively used in a wide variety of high quality cost effective and environmentally appropriate solutions.*"

For the SRI: "the future of steel in the single family, multifamily and commercial construction markets depends on the steel industry's ability to meet the emerging desires of the marketplace for energy efficiency, high performance, and reduced environmental impact".

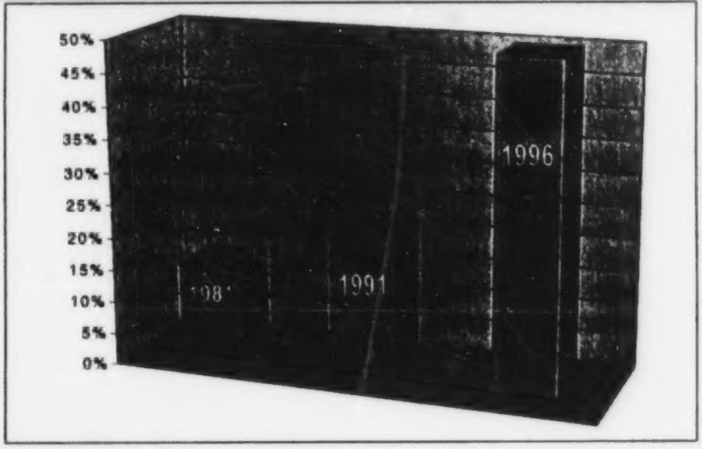
SMA

The Steel Manufacturers Association (SMA) mainly represents companies that produce steel from recycled scrap utilizing electric arc furnace (EAF) technology. (See Appendix F for a *Glossary of Steel Terms*) Using almost 100 percent scrap steel and EAF technology makes these plants -often referred as minimills- highly efficient and competitive and at the same time allows them to reduce their energy consumption and environmental impact. Here follows a brief account from the SMA about the deep changes of the steel industry in recent years:

"The steel industry in the United States has undergone a remarkable transformation since the 1970s. Much of this success can be attributed to the electric arc furnace (EAF) carbon steel producers, or 'minimills', which have emerged to become the most competitive steel makers in the world.

"The steel industry of the 1970s and early 1980s seemed to be in a perpetual downturn. Many steel companies went bankrupt or underwent reorganization. Others faced severe financial difficulty, reducing output by over one third in the period 1975-1985.

Figure 17: Share of EAF technology in North America



"Meanwhile, a new breed of steel producers grew in this chaotic period. At the time some large steel companies were reducing their output by one-third, a group of relatively small steel companies doubled their output by using EAF and continuous casting technology to make steel products from steel scrap.

"In 1981, these companies accounted for only 15 percent of US steel production. But in 1991, they accounted for 22.7 percent. Today, the EAF carbon steel producers account for nearly half of the steel making capacity in the US. From the 1980s onward they have continued to penetrate the

markets for higher quality, higher value-added products such as special bar quality steel, heavy structural, and flat-rolled sheet.

"Their growth can be attributed to several factors, the most significant being cost, efficiency, and quality. With low operating costs, and efficient, flexible organizational practices, the EAF steel producers were able to expand cost advantages and product quality.

"Today, the US steel industry is once again a vibrant, dynamic, internationally competitive industry. Competition is forcing inefficient and high-cost producers to streamline and cut costs wherever possible. The success of the US EAF steel producers helped to drive them to higher levels of efficiency and impelled other steel producers to emulate that success. "

SMA is North America's largest steel trade group with 59 North American companies that operate 111 steel plants and employ approximately 70,000 people. It has 48 members in the US, 7 in Canada, and 4 in Mexico. SMA's members use primarily scrap-based electric arc furnace (EAF) technology with recycled scrap constituting almost 100 percent of the materials input and together, they represent about 50 percent of North American production capability.

SSCI

The Steel Service Center Institute (SSCI) represents the interests of Canadian and American steel distributors and warehouse companies, often referred as the steel service center industry. Its membership includes over 400 service centers and nearly 200 steel producers in the USA and Canada. The objective of the SSCI is to inform, educate, and liaise with governments. For the SSCI, the service centers are...

"...the critical link in the supply chain connecting steel mills to manufacturers. Steel mills ... make metal in specific sizes and grades. Service centers add value and help manufacturers remain internationally competitive by inventorying metals and processing them to specific sizes, shapes and strengths."

International

IISI

Founded in 1967, the International Iron and Steel Institute (IISI) is a non-profit research organization whose members are steel companies, national and regional steel federations and steel research associations in 50 countries. The countries in which the member companies are located produce over 70 percent of the total world steel production. The IISI undertakes research into economic, financial, technological and environmental aspects of steel in the world. The IISI provides free publications on the application of steel in architecture titled "*The innovation in steel series for architects*", and to date, it has produced six brochures on different application of steel to architecture.

- *Multi-storey Buildings around the World* (published in 1991) covers the application of steel in medium rise office and administrative buildings.
- *Shopping Centers around the World* (1992) treats of the use of steel in arcades, galleries, and malls.
- *New Life for Old Buildings around the World* (1993) describes the use of steel in the renovation of factories, theatres, museums, schools, cloisters, and so on.
- *Passenger Stations around the World* (1994) covers bus, rail and metro stations, ship terminals.
- *Roofs and Facades around the World* (1995) deals with coated steel sheet in exterior applications.
- *Residential Construction around the World* (1996) covers the application of steel for housing, which provides many interesting examples of a wide variety of steel houses such as:

- Single-family houses. systems, modular constructions
- Single-family houses, individual forms, upscale houses
- Semi-detached houses
- Row houses
- Multi-family houses

According to the IISI:

"The interesting facet of steel's awakening in the residential market is that it cuts across a wide diversity of culture and geography. Steel roofing has become the standard for the harsh sun climate of Australia; steel framing is being used to replace brick and masonry in the United Kingdom and on the European continent; in North America, Scandinavia and Australia, steel offers an exciting alternative to timber framing and combustible roofing materials. In Sweden, steel frames offer flexibility in multi-storey residential projects. In Japan, steel is replacing wood because of its adaptability to automated prefabrication, its seismic resistance, and its permanence. In the developing nations, prefabricated steel units are providing shelter that can be assembled with untrained labour."

In 1995, the IISI hosted an international seminar on "*steel in housing*," which addressed many of the issues related to the promotion of steel in single family housing and low-rise apartments. In his opening remarks, the Secretary General of the Institute explained that:

" many of us (steel industry) made major marketing efforts in the housing field in the 50's, 60's and 70's. Yet with some exceptions such as Japan, few of these programs have had the success they deserved. Is this a matter […] of cost-competitiveness […] or did we fail to…understand the market drivers…"

This seminar was a turning point in the position of the steel industry in relation to the single-family market. It showed that many countries in the world were developing steel housing to a various degree. The countries that made the greatest progress in the use of structural steel were Japan, Sweden, and Australia.

- **Japan** benefits from a huge housing market of more than 1,500,000 housing starts a year, a strong and highly developed industrial infrastructure, and wide acceptance of prefabricated construction that represents more than 20 per cent of new houses. During 1993 about 368,000 houses were built with a steel frame in Japan, for a market share of 25 percent. Due to more strict environmental requirements, which negatively effect the wood frame construction, the Japanese steel organization Kozai Club, forecasts a doubling of the number of steel houses in the next decade.
- **Sweden** has a long tradition of steelmaking with a strong development for steel in the medium rise building (see SBI.) Market share for steel in housing was 8.6 percent in 1993. The housing industry has developed many efficient solutions for prefabrication using steel structure, floors systems, light wall panels, metal roof, and self-contained bathroom and kitchen units.
- **Australia** also has a strong tradition of building with steel and is one of the pioneers in the field for using steel frames in residential construction. The large builders often act as project managers and subcontract tradesmen who supply and install the major components, such as the plumbing, kitchens, roofing and external walls. The methods and construction solutions are maintained from project to project in order to ensure high efficiency. Today, in Australia, family houses with a steel frame are considered an efficient construction method and they have a large market share. Steel roofing has an 84 percent market share. Together with roofing with steel, the total amount of structural steel in a typical family house is 3 to 4 tonnes.

Some of the conclusions from the Steel in Housing seminar were:

- **Trends in the construction market.**
  - Fast erection is becoming increasingly important because land prices are increasing faster than income.
  - Current building techniques are labour intensive giving an advantage to steel.
  - Individualization of houses is a very clear trend today.
  - Environmental issues are becoming more influential.
- **Requisites for entering in the housing market:**
  - Builders and other professional groups must be educated.
  - Distribution channels must be developed.
- **Suggestion for improving the share of steel in the housing market**
  - Give more technical information concerning fasteners, fire, vibration, acoustics, strength, corrosion, and thermal properties.
  - Create award for innovative steel design.
  - Promote demonstration projects.
  - Direct programs to developing countries.
  - Reduce environmental impact and embodied energy.
  - Improve regulatory acceptance.
  - Share information worldwide.

SCI

The Steel Construction Institute (SCI) is the world's largest research and technical organization supporting the use of steel in construction. The objective of the SCI is to develop and promote the effective use of steel in construction. It is based in the UK where steel enjoys the highest market share in the world in the most important construction sectors. 40 percent of bridges, 57 percent of commercial buildings, and 95 percent of industrial buildings are using structural steel in UK.

The institute produces numerous publication on all aspect of steel construction, including topics related to residential construction such as: architecture, composite construction, connections, construction practice, corrosion protection, fire engineering, and light gauge steel.

Another important publication in the context of the use of steel in housing is "*Architecture and Construction in Steel*", edited by A. Blanc, M. McEvoy & R. Plank. This book is a comprehensive guide to the successful use of steel in building and it is a unique source of reference on all aspect of architecture in steel, including steel houses. It contains the contributions from 29 leading architects, engineers and lecturers, which are presented in six sections: History of iron and steel construction, materials, principles of steel framing, steel construction, secondary steel elements, and outstanding contemporary steel architecture. The book is illustrated with over 1000 photographs, plans, section drawings and construction details from all around the world.

Another notable publication from the SCI is "*Design for construction*", which outlines the effects that basic design decisions can have on the overall buildability and cost of a building. An excerpt from the summary follows:

"There is a common misconception that the lowest cost solution for a steel-framed building will be the structure containing the least tonnage of steel. However, in the current climate of relative material and labour costs this is not normally true. Minimum weight usually equates to complexity, involving extensive local stiffening, and stiffeners have a large influence on the cost of fabrication and erection. As a rule-of-thumb, for every fabrication hour saved, 100 kg of steel could be added to the frame without any cost increase.... Complexity also lengthens fabrication and erection periods.

Longer construction periods may delay the return on a client's investment. Design decisions, which affect construction time, are just as important as those directly related to material costs."

The SCI publishes also many excellent references on steel decking, connections details, construction guidelines and practices. Unfortunately, these often relate to European standard and may not apply to the North American context.

SBI

The Swedish Institute of Steel Construction (in Swedish, Stålbyggnadsinstitutet or SBI) is an information, research and development organization for the use of steel in construction.

The SBI is currently undertaking extensive research in housing, environment and high-strength steel with the goal of becoming of the global leaders in these areas. Sweden has a long tradition of steelmaking and shares many similarities with Canada in its climate and wood-based industry. In recent years, Sweden has made great progress in steel building systems as pointed by this article from the Swedish technical journal *Nordic Steel and Mining Review 1997*, written by Helena Burstrand and Lars Cederfeldt and reproduced with the permission of the authors.

"The construction industry is in great need of enhancing its efficiency. In the past 20 years, the building industry has not developed in a way corresponding to the greater part of the manufacturing industry. The real production costs for the construction industry have instead increased. The reason why the building industry have went into stagnation, is mainly due to conservatism with old traditions, where development is impeded by the feeling that building is a local business with limited competition and each new building project being regarded as unique. The building process today is therefore still more a trade than an industry.

"...The Swedish Institute of Steel Construction (SBI) works intensively together with the construction industry on new high competitive systems for housing. ...What makes the work unique is that we developed the whole building system, including for example the planning process, building services, the architecture and effective production methods for prefabrication of wall and floor elements. The objective is to reduce the building costs dramatically by making the building process more efficient. ...

"One important part is to use the modern information technology (IT) with an objective to develop and to make the building process industrialized. ...Using 3-D IT as an intelligent information carrier, and by using automated processes that assure the quality of the production chain, profitability for the players in the industry can be achieved by industrializing the building process. ...

"...the idea that each part must be procured in competition and that today's site structure is the best suited for carrying out a building job, must be reviewed. The building process must be more like the structure of the fixed industry, based on co-operation between the parties and an industrial production with prefabricated elements and components that can be erected quickly on site.

"...As information is stored in one place only, and is automatically transferred without manual intervention, it is possible to achieve the target of zero errors. 3-D design permits the correct amounts of building materials to be delivered in the exact form to the site or the site factory for efficient assembly. We have obtained an industrialized process that is characterized by:

- *Better working conditions.*
- *Ecological building.*
- *Functionally correct buildings.*
- *Quality.*
- *Radically shorter design times.*
- *Lower costs.*

"So far, the building process till the building site have been developed. The next step is to learn from the steel industry about production methods and how to rise the productivity in all parts. The Swedish building system are already into markets as Hungary, Germany and Russia and the interest from several other countries stimulates us to further development of the most efficient building system for housing."

The SBI has been very active in the past years looking for alternatives to the high cost of housing in Sweden. One of the solutions considered is to transfer the North American technology of light-gauge steel studs and to apply it to single-family housing and low-rise residential buildings. Another solution is the use of structural steel and the SBI has published a comprehensive report on all the aspects of this technology such as: cost, fabrication, structural properties, acoustic, fire, corrosion, environment, connections, floor systems, wall systems, services, self-contained bathrooms, accessories, and so on.

Because of its leading edge research program in steel in housing, the SBI is one of the most advanced construction organizations in the world. Furthermore, the similarity between Sweden and Canada in relation to climate and wood predominance in the construction market makes the experience of the SBI worthwhile considering in the context of the application of steel to Canadian housing.

Design

The design and construction of structural steel require special skills and knowledge. As a result, (see Chapter 7) building with structural steel involves generally three categories of design professionals:

- Architects.
- Engineers.
- Steel detailers.

Because the quality of their work is often critical to the safety of a building and its users, the activities of architects and engineers are strictly regulated by codes and laws. To carry out their professional activities, an engineer or an architect must be registered by a local association or institute that acts as an auto-regulating and enforcing authority. Here follows a list of the main professional organizations:

RAIC

The Royal Architectural Institute of Canada, established in 1907, is a voluntary national association representing more than 3,000 professional architects from every region of the country. It works towards a future in which Canadians will view their total environment, both natural and built, as their most important asset, and the Institute's members as essential to its creation and maintenance. The RAIC advances the cause of architecture and its practice in Canada. It provides the national framework for the development and sharing of architectural excellence.

The Institute creates forums, which bring together leading work in the field of architecture and architectural practice for critique and debate, recognition of excellence, and substantive documentation as a basis for shared learning by the broader architectural community. The Institute's program addresses issues of design, building technology, and practice by focusing activities in five areas: publications, symposia & exhibitions, research, awards, and practice committees.

CCPE

The Canadian Council of Professional Engineers (CCPE) is the federation of twelve provincial and territorial associations, which represent more than 160,000 Canadian professional engineers.

The following engineers associations are members of the CCPE:

- Ordre des Ingénieurs du Québec
- Association of Professional Engineers and Geoscientists of Newfoundland
- Association of Professional Engineers of Nova Scotia
- Association of Professional Engineers of Prince Edward Island
- Association of Professional Engineers of New Brunswick
- Professional Engineers Ontario
- Association of Professional Engineers of the Province of Manitoba
- Association of Professional Engineers and Geoscientists of Saskatchewan
- Association of Professional Engineers, Geologists, and Geophysicists of Alberta
- Association of Professional Engineers and Geoscientists of the Province of British Columbia
- Association of Professional Engineers, Geologists & Geophysicists of the Northwest Territories
- Association of Professional Engineers of the Yukon

To operate as a professional engineer, an engineer must be registered in the local association in the province where he or she works. The associations auto-regulate their members through a code of practice and practice review. They are particularly vigilant in the field of structural engineering.

Professional engineer associations become increasingly aware of the influences that the profession may have on sustainability. One of the most advanced is the APEGBC, the Association of Professional Engineers and Geoscientists of the Province of British Columbia, has recognized that:

"There is, however, increasing agreement that current practices have resulted in significant problems today and will continue to do so unless answers to these problems (of sustainability) are found very soon."

As a result the APEGBC has produced sustainability guidelines, which recommend that engineers and geoscientists:

1. Develop and maintain a level of understanding of the goals of, and issues related to, sustainability.
2. Take into account the individual and cumulative social, environmental and economic implications.
3. Take into account the short- and long-term consequences.
4. Take into account the direct and indirect consequences.
5. Assess reasonable alternative concepts, designs and/or methodologies.
6. Seek appropriate expertise in areas where the Member's knowledge is inadequate.
7. Cooperate with colleagues, clients, employers, decision-makers and the public in the pursuit of sustainability.

ACEC

The Association of Consulting Engineers of Canada (ACEC) groups the engineers involved in design services for capital projects. (See Chapter 7.) It represents more than 700 independent consulting engineering firms operating across Canada. Member firms range in size from single-person operations to multi-national companies employing over 5,000 people. Membership in the ACEC is voluntary. However, to be admitted as members, firms must meet strict criteria such as providing independent consulting engineering services, adherence to high ethical standards, professional responsibility, and at least 50 percent of a firm's management must be engineers. The overall mission of the Association of Consulting Engineers of Canada is to promote and safeguard the business and professional interests of the Canadian consulting engineering industry in Canada and abroad.

According to ACEC, engineers have made in recent years an enormous progress in

"Automating their own operations through a variety of ways:

- *proprietary computer-aided design and drafting (CADD) software systems capable of tripling productivity*
- *interactive CADD systems with on-line databases that automatically issue change notices, revised drawings and updated material bills*
- *computer-assisted engineering design (CAED) systems, which calculate elements such as structural analysis, foundation design, slope stability and earthquake resistance*
- *systems that tie CADD systems directly into construction software for estimating, project scheduling, cost control and materials tracking.*

"Project management innovations and proprietary construction techniques can reduce construction costs. Currently, most companies work with several independent databases, moving control from one to the other during successive stages in design and fabrication. Emerging computer-based construction management systems integrate these databases with procurement decisions. They smooth the flow of work, reduce inventories during construction, improve productivity and cut costs. Superior technological expertise can save on operating costs. Most successful design firms have the expertise not only to design more efficient plants, but also to make incremental improvements over previous designs. Proprietary processes open doors to emerging or established markets. "Improved processes" lower design, construction or operating costs, and "new processes" make the process cost-effective the first time, thereby opening up new markets. By developing proprietary process technology, firms may be able to insist on handling contracts on a turnkey basis, thereby avoiding the need for separate design and construction bids. Such turnkey contracts allow consulting engineering firms to minimize project life-cycle costs, rather than just design costs."

NISD

The National Institute of Steel Detailing (NISD) is the professional organization representing independent detailers and their interests in the steel construction industry. The NISD has members in US and in Canada. Its objective is to create a better understanding between detailers, fabricators, architects, engineers, and the general public.

Building systems

In recent years, the fabrication and installation of pre-fabricated steel buildings and components has become a multi-billion dollars industry in North America. The interests of businesses that deal with building system are represented by a wide-range of institute and organizations:

SDI

The Steel Deck Institute (SDI) has the objective to standardize the design, engineering, manufacture, quality control, and construction practices applicable to cold-formed steel decking. The main uses of steel decks are roofs, floors, and to serve as a permanent form and positive reinforcement for concrete floor. Steel decking is complementary to structural steel. Therefore, the SDI is a useful source of information and standard for developing structural sound systems.

For the SDI, the advantages of steel decks are:

- versatility and availability in a wide range of depths and rib spacing, with and without stiffening elements, with and without acoustical material, cellular and non-cellular, and in varying thickness
- structural strength achievable with less weight

- attractive appearance when left exposed
- ability to be installed in all weather
- good fire ratings
- uniform quality and conformity to standards
- proven durability, with steel decks performing satisfactorily for more than 50 years
- economy and value, determined by combining initial costs, life-cycle costs, and overall performance.

The SDI publishes the *"Design Manual for Composite Decks, Form Decks, Roof Decks, and Cellular Metal Floor Decks with Electrical Distribution, a definitive guide to the proper design and specification of steel decks"*. This manual contains standard for steel floor decks, roof decks, and related products addressing:

- design thickness
- manufacturing tolerances
- site storage and erection recommendations
- accessories, such as sump pans, ridge and valley plates, and cant strips
- specifications for composite steel floor deck, non-composite steel form deck
- steel roof deck, and cellular metal floor deck with electrical distribution
- standard roof deck sections and load tables for narrow, intermediate wide rib and deep rib decks.

MBMA

The Metal Building Manufacturer Association (MBMA) represents the interests of the major building systems manufacturers and builders in the US. The market for building systems is quite large. According to the MBMA, in 1995 the sales were 2.21 Billion U$. In US, 36 percent of the commercial buildings and 12 percent of community buildings (recreational, schools, churches, institutional, and so on) use building systems.

For the MBMA, the main characteristics of building systems are:

- End-use flexibility and diversity in design and appearance.
- Ease of expansion by "pushing" the end walls.
- Low maintenance of components and in recent years, exterior surface treatments that allow extended warranties and require little or no maintenance.
- Increasingly advanced and aesthetically pleasing design
- Computer Aided Design (CAD) that is a natural complement to the use of standard components to fit customized applications. Components can be defined using CAD, then moved and adjusted until they fit the application. They can then be downloaded into a computer-aided manufacturing process and applied to a factory mass production.
- Clear span that allows internal layout flexibility, the metal building system manufacturing process enables the customer's application to determine the shape and configuration of the building and as result, it is not necessary for a customer to redesign his operation around a conventional building.
- Low environmental impact: Speed of construction and minimal concrete requirements for metal building systems permit rapid installation in ecologically sensitive environments with little or no environmental impact.
- Builder network: Metal building systems are marketed, sold and erected through franchised builders specially trained by systems manufacturers. The builder acts as general contractor and provides construction services. This highly successful concept generates the design/build approach

to construction. The design/build process places single-source responsibility for project design, pricing and construction in the hands of one person, the contractor.

Modern Trade Communications

Modern Trade Communication (MTC) is a US private organization that publishes trade magazines, which cover metal construction and design markets. It is a good source of information on the metal building systems, steel technology, components, steel roofing and siding. The magazine often provides case studies and outstanding examples of the application of steel structure in housing. Subscription is free in the US and is available in Canada at a modest price. The three main magazines published by MTC are:

- Metal Construction News, published monthly, for contractors and erectors involved in metal buildings, metal roofing and metal siding. It mainly addresses industrial and institutional metal building.
- Metal Architecture, published monthly, for architects and design professionals involved in metal buildings, metal roofing, and metal wall panel systems. It addresses all aspects of steel building, including case studies of steel houses.
- Metal Home Digest: bimonthly for homebuilders, roofers and developers interested in the residential steel framing and metal roofing/siding markets. This magazine addresses steel houses exclusively, mostly with steel stud technology. It provides, also, a growing number of examples of steel houses using structural steel.

Manufactured Housing Institute

The Manufactured Housing Institute (MHI) is a trade association for manufactured housing in US. It represents all segments of the industry, including manufacturers, component suppliers, retailers, community owners and operators, state associations, and financial institutions involved in the lending and insuring of manufactured homes.

Today's manufactured houses are very seldom made with steel. However, the statistics of the MHI can be used to show that the market for prefabricated or manufactured steel houses is very promising.

- Manufactured homes account for more than a third of all new single-family homes sold in the USA.
- Approximately 18 million people - over 7 percent of the U.S. population - live in 7.3 million manufactured homes.
- 88 percent of manufactured home homeowners report satisfaction with the manufactured housing lifestyle.
- Manufactured housing retail sales were estimated at U$11.9 billion in 1995.
- The average sale price of a manufactured home was U$33,500 in 1994. Single-section homes average U$23,900, while multi-section homes average U$42,900.

These statistics show that the house market is open to low-cost, fast, prefabricated housing, which are the main features of steel houses as it was explained in Chapter 3. Therefore, the use of steel technology that focuses on speed, flexibility and economy, by the application of prefabrication and automated industrial processes, could compete successfully in the housing market.

CHAPTER 6 – COMPLIANCE WITH BUILDING CODES

The use of steel in single-family housing construction raises the question of compliance with local Building Codes, which are all based on the National Building Code of Canada (NBC.) The intent of the Codes is to provide the minimum requirements for building safety related to health, fire protection, and structural adequacy. The NBC applies different rules according to categories determined by the main occupancy of the building. Single-family residential houses, referred to as group "C" buildings, with an area smaller than 600 m2 and a height no greater than 3-stories are specifically covered by Part 9 of the NBC, *housing and small building*. To simplify the task of home designers and builders, Part 9 contains detailed requirements for the residential construction and is based on prescriptive rather than performance standards. Buildings subject to Part 9 are generally exempt from the more stringent and complex requirements of other Parts of the NBC. A steel house must follow the requirements of Part 9, like any other house, but in addition, the design of its structure must comply with Part 4, *Structural Design.*

Structural Design

Unlike wood frame construction, the use of structural steel is not described in Part 9 and therefore is subject to the requirements of other parts of the NBC. In fact, Section 9.4 of the NBC requires structural steel members in residential housing to be designed in conformance to Part 4. The only exception is for steel beams supporting wood floors and selected according to the Span Table 9.23.4.A. (See discussion of the results of this table in Appendix D). This table cannot be used to calculate a complete structural system; therefore, each steel house must be individually designed in accordance with Part 4 of the NBC.

Part 4 provides the rules for calculating a structure, and specifies the loads to be used in design calculation as well as the design methods and applicable standards. The intent of Part 4 is to ensure:

- Sufficient structural capacity to resist without structural failure all loads and influences that may reasonably be anticipated during construction and during the expected service life of the building.
- Sufficient structural integrity to absorb local failure (due to an accidental event) without widespread collapse.

The Code has three main requirements for steel structures:

1) The designer of the structure must be a professional engineer. (Article 4.1.1.2.)
2) The design of structural steel must conform to the Canadian Standard CAN/CSA-S16.1-M *"Limit State Design of Steel Structure"*. (Article 4.3.4.1.)
3) Fabricators and erectors for welded construction must be certified by the Canadian Welding Bureau. (Article A-4.3.4.1. in Appendix A)

1) The designer must be a professional engineer.

A steel house requires the services of a professional engineer. This clause ensures that persons skilled in the area of structural design and evaluation carry out the requirements of Part 4. The engineer, often referred as the Structural Engineer of Record (SER) or, must ensure that his design meets the intent of the Building Code and file Letters of Assurance to that effect. The duties of the engineer, as described in Section 2.6. of the Code, consist of coordinating the design work and the field review.

- The design work includes structural analysis, configuration and sizing of elements, and connection details. The objective is to insure that the design complies with the Building Code and other safety regulations. The SER must place his seal or *stamp* on all the plans related to the structural components of the house.
- The field review involves review of the work on site and at fabrication locations where building components are fabricated. The engineers must keep a record of all the field reviews and of any resulting corrective actions.

The SER and the client must agree on the scope of the engineer's service. Normally, the SER is responsible only for the primary structure such as the beams, trusses, columns, and main structural elements. In some case, he may also be responsible for the secondary structure, such as curtain walls, cladding, and seismic restraint for architectural elements. The SER is not responsible for the steel connections that are usually designed by another engineer, and often referred to as the Specialty Structural Engineer (SSE), who works with the steel detailer.

The scope of service provided by the engineer may vary according to the complexity of the project. The basic services consist of:

- Conceptual Design: helping the client and the design team to define the structure requirements
- Design Development: Prepare preliminary structural analysis and design calculation for the typical structural elements of the primary structural system.
- Final Design: Provide detailed structural calculation, structural drawings and specification for connection to be designed by the Specialty Structural Engineer. Structural calculations include: design criteria, vertical and lateral load analysis; structural drawings include foundation plans, size and location of beams, columns, trusses, and all other structural elements. The final plans must also include specifications on standards, codes, materials, QA/QC, performance criteria for the SSE.
- Construction: Conduct performance inspection of the structural components of the project including shop drawing review and site visits to observe the quality and progress of the construction of the elements designed by the engineer.

Part 4 of the NBC is less prescriptive than Part 9 and gives design professionals more latitude and flexibility, provided that their design has met the intent of the Building code.

Local associations of professional engineers regulate the practice of engineering. (See Chapter 5.) Codes of practice for engineers are increasingly more stringent on the conditions required for designing structures such as specialization in the structural engineering field, years of experience, in-house or peer conceptual, and detailed review. Furthermore, engineers supervising steel details, connections, and welding (SSE) must get a certification from the Canadian Welding Bureau. (See below).

2) The design must conform to the "Limit State Design" Standard

The CAN/CSA S16.1-94 Standard *Limit State Design of Steel Structure* provides the requirements for analysis, design, detailing, fabrication, and erection of steel structure. The intent is to provide *"a satisfactory level of integrity for most steel structures"*.

The Limit State Design (LSD), introduced in 1974, checks the performance of a structure against various limiting conditions at appropriate load design. The limiting conditions for structural steel are ultimate limit state and serviceability limit states.

Ultimate Limit State relates to safety issues, such as exceeding carrying capacity or overturning. In essence, the design must ensure that the maximum strength of a structure and all its elements is greater than the maximum loads that could be imposed upon it with a safety margin. These maximum loads are the *"ultimate limit states"*.

Serviceability Limit State ensures that, when subjected to service or live loads, the structure will behave satisfactorily and not have excessive deflection, vibration or permanent deformation.

The loads for the Limit State Design are provided in Section 4.1.2 and Sections 4.1.5 to 4.1.10 of the NBC and consist of:

D: Dead load or weight of the structural member and all construction material supported by the element. (Article 4.1.5.)

L: Live load due to occupancy, snow, ice and rain. (Article 4.1.7)

Q: Live load due to wind or earthquakes. (Article 4.1.8 and 4.1.9)

T: Influences resulting from temperature changes, shrinkage, or from differential settlement. The temperature loads due to contraction and expansion caused by temperature change are often overlooked, although they may be important in a steel structure. Steel expands by 0.0011 percent per degree Celsius and if both extremities are fixed, temperature changes may create substantial additional loads. The temperature load for steel is calculated according to the formula:

$$\text{Ft (MPa)} = 200{,}000 \times 11.7\ 10^{-6} \times \Delta T$$

with ΔT= difference of temperature in ° Celsius

(For example, if the temperature rise 20°C, a steel beam restrained from expansion will be under an additional stress of $200{,}000 \times 11.7\ 10^{-6} \times 20 = 46.8$ MPa.)

The safety check for strength and stability of structural steel must use the factors provided in Article 4.1.4.2. and the elements must satisfy the following formula

$$\phi R \geq \alpha_D D + \gamma\psi(\alpha_L L + \alpha_Q Q + \alpha_T T)$$

where:

R = Nominal resistance of a structural element, function of the yield stress of the steel.

ϕ = Performance factor, generally 0.9 for steel components.

α_D = Dead Load Factor = 1.25

α_L = Live Load for occupancy, snow, ice, etc. = 1.50

α_Q = Wind factor = 1.50 or Seismic factor = 1.00.

α_T = Temperature Load factor = 1.25

γ = Importance factor = 1 for residential construction.

ψ = Load combination factor, which takes into account the probability of the loads to occur at the same time. This factor equal 1.0, 0.70 or 0.60 depending if the number of loads used in the formula are respectively 1, 2 or 3.

The serviceability must be checked with loads calculated according the formula (Article 4.1.4.3.)

$$\text{Service load} = D + \psi(L + Q + T)$$

3) Fabricators and erectors must be certified

This clause ensures that the fabricators and erectors take the responsibility for structural welding and that they have the capability to make structural welds of the quality assumed by the Standards. To receive certification, a steel fabricator must submit his welding procedures for approval by the Canadian Welding Bureau (CWB.) The welding supervisors of the company must pass an examination on welding Standards and procedures and the welders must pass a welding test (a *ticket*). The company must also employ or retain the service of a registered engineer to supervise the steel detailing and the design of the connections and welding. The CWB requires the engineer to pass an examination on Welding Standards CSA W47.1 and CSA59 as well.

Structural steel construction standards

Canadian structural steels for general construction and engineering purposes are covered by the standard CAN/CSA G40.21-M, "*Structural Quality Steels*" which specifies their mechanical and chemical properties. Today in Canada, CAN/CSA G40.21-M 350W is the standard for weldable steel normally specified for building construction. The number 350 indicates that the yield point is 350 MPa and the letter "W" that the steel is "weldable".

The Canadian Institute of Steel Construction (CISC) publishes the *Handbook of Steel Construction,* described in Chapter 5, which contains the Limit State Design Standard and practical information for designers and fabricators on how to use steel according to these Standards and how to design and fabricate connections, columns, and beams. It also contains the *CISC Code of Standard Practice for Structural Steel,* which is a compilation of usual industry practices relating to the design, fabrication and erection of structural steel. The code of practice defines the so-called *"shop drawings"* or fabrication and erection documents that may be necessary to complete a steel construction project. Shop drawings may contain five distinct documents, but not all of them are required for the construction of a steel house:

- **Connection details**: prepared in advance to the shop details and submitted for approval to the designer or professional engineer.
- **Shop details:** containing the complete information for the fabrication of the elements of the structure and submitted for approval to the professional engineer.
- **Erection diagrams:** general arrangement drawings with the principal dimension of the structure and all information necessary for assembly, including the size and location of anchor bolts, submitted for approval to the professional engineer
- **Erection procedures:** construction methods, erection sequence, temporary bracing, shoring, and shipping instructions.
- **Field work details**: information for modifying structural elements on the job site, submitted for approval to the professional engineer

Except when otherwise specified in their contracts, CISC's members must abide by the practices described in this code.

Fire protection

Although steel is noncombustible, it has poor resistance to fire and will buckle and collapse under high temperature. Therefore, to achieve a fire-resistance rating, the structural steel members must be protected. (Article 9.10.7.1., Article 9.10.8.1. and Table 9.10.8.A.) Chapter 2 of the supplement of the NBC describes different ways of providing fire-protection to steel beams and columns, such as encasing the elements in drywall, steel-sheet, mineral wool or concrete. Protection of exposed steel includes applying a special fire-resistant paint, installing sprinklers, or if the elements are hollow, filling them with water or concrete.

Through the FireCam program, the Canadian Institute of Research in Construction (IRC) has created models for evaluating the performance of structural members in severe fires. This type of research allows assessing the fire resistance of new and evolving technologies for which standardized design approaches may not exist. The IRC is currently developing models in collaboration with the steel and concrete industries.

For single-dwelling units, the NBC does not require fire-protection provided that there is no other dwelling above or below it. (Article 9.10.8.9). Therefore, the structural steel in individual single-family steel houses may be left exposed and unprotected.

Finally, a structural steel house can be made entirely with noncombustible materials: steel, concrete, glass, fiberglass insulation, and gypsum boards. This characteristic is useful when the NBC requires noncombustible construction. This is the case when the spatial separation between building is such that the unprotected opening must not exceed 10 percent and when the house contains more than one dwelling. (Art. 9.10.14.11)

Cost of compliance

Compliance to the additional code requirements described above may have an impact on the total cost of the project

Cost of engineering supervision.

Part 4 requires engineering services for each house built, which may cause the project to become more costly to the homeowner and more complex for contractors and house builders. This issue could be the major obstacle to a wide application of the technology.

Local associations of Professional Engineers and Consulting Engineers have established fee guidelines that reflect the value of services received by the clients. The services provided by the engineering profession cover a wider range of activities that are usually grouped in seven categories:

1. Advisory, conceptual sketch.
2. Preliminary design
3. Final design and contract documents
4. Tender calls
5. Construction and contract administration.
6. Project management.
7. Construction management.

Designing and building a steel house requires only a few of the above services. As described earlier, these *Basic Services* are contained in categories 2 through 5 and generally include:

- Preliminary design and schematics
- Detailed design
- Review of shop drawings
- Field review

The fees are based on one of four methods of calculation:

- Method 1, **Time basis**: The consultant charges for every hour of work on the project at an hourly rate, which equals to the payroll cost multiplied by a factor for overhead and profit. The fees may go as high as 2.5 times the payroll cost.
- Method 2, **Percentage of cost of construction**: That may vary from 5 percent to 10 percent depending on the type of service and the size of the project. For a steel house, the structural engineering services will be pro-rated to the cost of construction of footing, foundation, structural steel, steel floor and roof decks, and concrete slabs. This method is seldom used when the cost of construction for an individual discipline is under $300,000 which is generally the case for residential construction.

- Method 3, **Cost Plus a Fee**: Same as method 1 except that the factor does not include profit. In addition to time charges, the engineer is paid a stipulated sum or a percentage of the total construction cost.
- Method 4, **Fixed Fee or Lump Sump Contract**. Suitable when the scope of the project is well defined.

The fees are negotiable and depend on the market, the size of the project, its extend, and the quality of the service provided. Each of these methods has its advantages and disadvantages for both the engineer and the client.

Method 1 has more risks for the client, and Method 4 more risks for the engineer.

Method 2 may create a potential conflict of interest because good engineering often decreases the total cost of the project and, as a result, the engineer's fee.

The selection of a method will largely depend of the type of project:

- For individually designed house, and prototypes, where the extent and difficulty of the work is not well identified, Method 1 or 3 are the most likely choices.
- Method 4 should be the preferred solution for repetitive implementation of the same design or construction of modular building systems because a fixed design cost is the most likely to receive acceptance by the housing market.
- For large projects, such as development of multiple housing, Method 2 or 4 could apply.

Although the fees may be relatively low compared to the total cost of the house, the engineer's service may become, or be perceived as, an unwanted additional cost to the project as well as a source of inefficiency.

Good design and planning may attenuate the impact of engineering cost or even result in total cost reduction. The extra cost for engineering can be minimized for the following reasons:

- Early involvement and close collaboration by the engineer in the design and building process results in overall project cost saving because of a more articulate design and better integration between the structure and other elements of the building. (See discussion in Chapter 3 "Reason #4" and Appendix A 3.1 "Conservation of Material".)
- Good design usually pays by itself by minimizing labour and material. (See Chapter 3: Reason #1: "Steel houses are cost-effective".)
- A building system approach, the use of standard elements and similar designs, and the computerizing of the whole design process reduce engineering costs.

The issue of increased cost for engineering design has been raised and addressed by the Light Steel Framing (LSF) industry. (LSF is also called steel studs framing) The CSSBI, which represents the interest of the LSF industry, is actively pursuing the goal of setting performance requirements for LSF similar to those addressed in Part 9 of the NBC for wood frame construction. (See Chapter 5 for a description of CSSBI.) The Canadian Construction Materials Center (CCMC) is presently developing the technical criteria for LSF. Located at the Institute for Research in Construction (IRC) of the National Research Council of Canada (NRC), the CCMC offers to the construction industry a national evaluation service for all types of innovative materials, products, systems and services. The following describes the CCMC's program related to the certification of LSF.

"CCMC, in partnership with the Canadian Sheet Steel Building Institute (CSSBI), is creating a mechanism whereby lightweight steel framing (LSF) products can be used in housing and small buildings - covered by Part 9 of the NBC - thus helping LSF manufacturers get their product to market."

Al Caouette, Unit Head of IRC's CCMC technical evaluation services explains:

"At present, every construction using lightweight steel framing is individually designed in accordance with Part 4 of the NBC - Structural Design. This means that an engineer's services are required for each house built, which increases the cost to the home owner."

"Based on performance criteria that will be developed by CCMC, CSSBI will create a set of construction requirements for steel studs, joists and roof rafters equivalent to those currently in place in Part 9 of the NBC for wood-framed buildings. These requirements will also be incorporated into the CSSBI Design Manual. In addition, CSSBI will develop a quality assurance manual governing the manufacture of LSF and an installation manual outlining how LSF products should be combined to form a complete building system.

"The performance criteria to be developed by CCMC will be used to create a technical guide that addresses all major factors affecting the use of lightweight steel framing - heat transfer, air leakage and condensation control, and structural performance of LSF assemblies. The structural requirements will include vibration characteristics for floor joists.

"Each LSF manufacturer will have its proprietary products evaluated against these requirements to determine compliance. Once this evaluation has been successfully completed, the manufacturer will be able to market these proprietary products to the construction industry as meeting the requirements of the NBC, Part 9.

"CCMC has also developed an evaluation guide for air barrier systems for low-rise construction that can be used to evaluate the suitability of air barrier systems for use in steel stud wall assemblies."

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A similar approach could be used to create a set of construction requirements for standard structural steel systems made with simple and modular post and beam elements and standard connections. The CISC's *"Handbook of Steel Construction"* could form the basis for a "Steel House Manual" and existing CSA Standards could provide the support for quality control. The CCMC could then evaluate the components of a pre-fabricated steel house system to determine compliance against these requirements. After successful evaluation, the steel house's manufacturer would be able to market its system as meeting the requirements of the NBC, Part 9.

Cost of Limit State design approach

The Limit State Design approach is more efficient than the Allowable Stress Design (ASD) that it has replaced. Therefore, calculating the structure according to Part 4 does not bring any cost penalty. At the contrary, the LSD methodology combined with the greater flexibility left to the designer result in a more efficient, lighter, and more economical structure.

Cost of fabricator certification

The initial cost of certification by the Canadian Welding Bureau is approximately $3,500 for a steel fabricator with 8 welders. The annual maintenance of the certificate is $1,500. These costs are generally a small fraction of production expenses and are included in the fabricator overhead costs.

Cost of fire protection

The NBC does not require the steel structure of single-family housing to have fire protection. If the house has a secondary dwelling, the steel needs a fire rating of 45 minutes, which can be achieved by simple, low-cost techniques such as covering the elements with drywall, applying a fire resistant paint, or installing sprinklers. The extra-cost of protecting the steel therefore seldom exceeds the cost of protecting an equivalent wood frame construction.

Cost reduction opportunities

A building system approach will reduce significantly the administrative costs by reducing the number of trades involved in the building process. Figure 18 shows that a steel house, built in a conventional way, requires the intervention of six different entities: Architect / designer, steel detailer, engineer, steel fabricator, general contractor, and suppliers. At the other hand, the system building, shown in Figure 19, require only 2 entities: the designer and the building system manufacturer, the latter regrouping most of the construction activities.

Conclusions

A steel house must conform to the structural design requirements of Part 4 in addition to the general requirements of Part 9 that are common to all single-family houses. It results in additional costs for engineering supervision of the design and construction of the steel structure. A better integration of engineering in the whole design and construction process can greatly reduce or even eliminate these extra costs.

Other requirements of the NBC related to the use of steel are straightforward and compliance can be achieved at low or no extra cost.

Figure 18: Conventional building process of a steel house

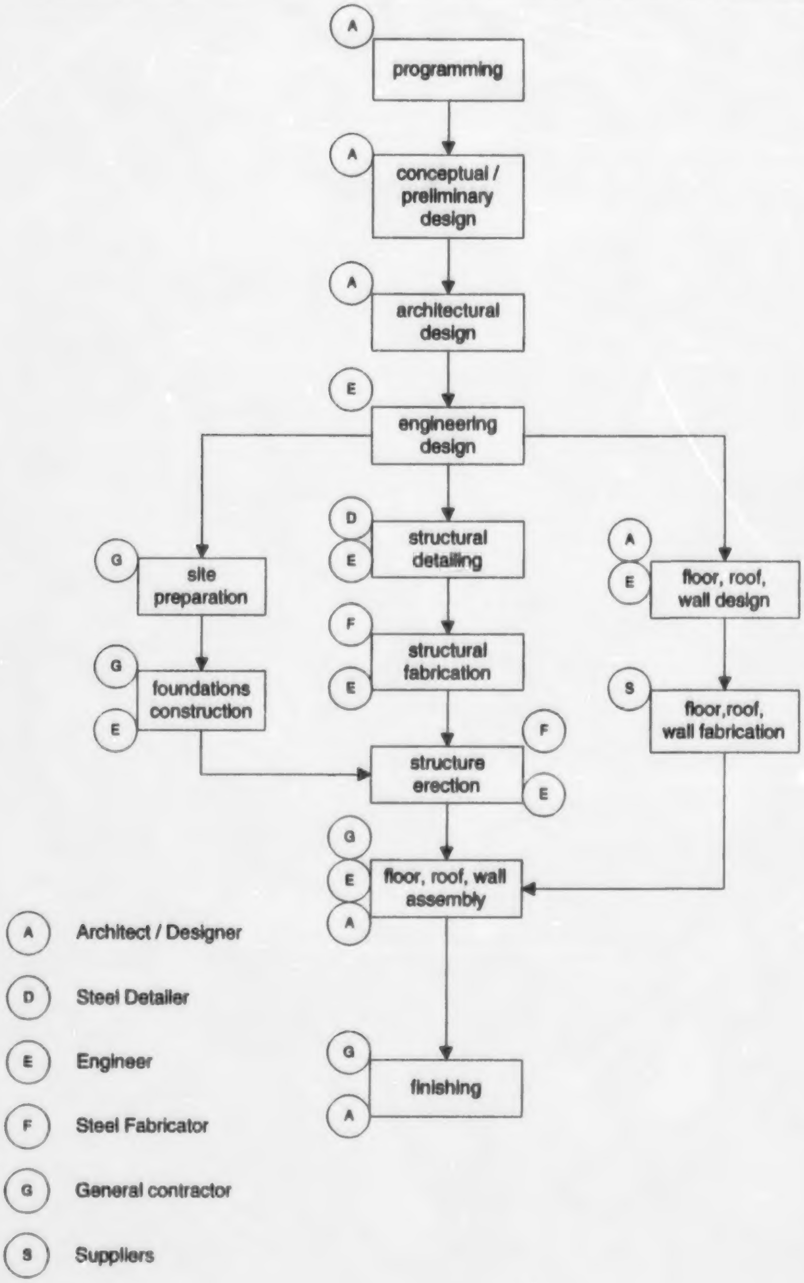
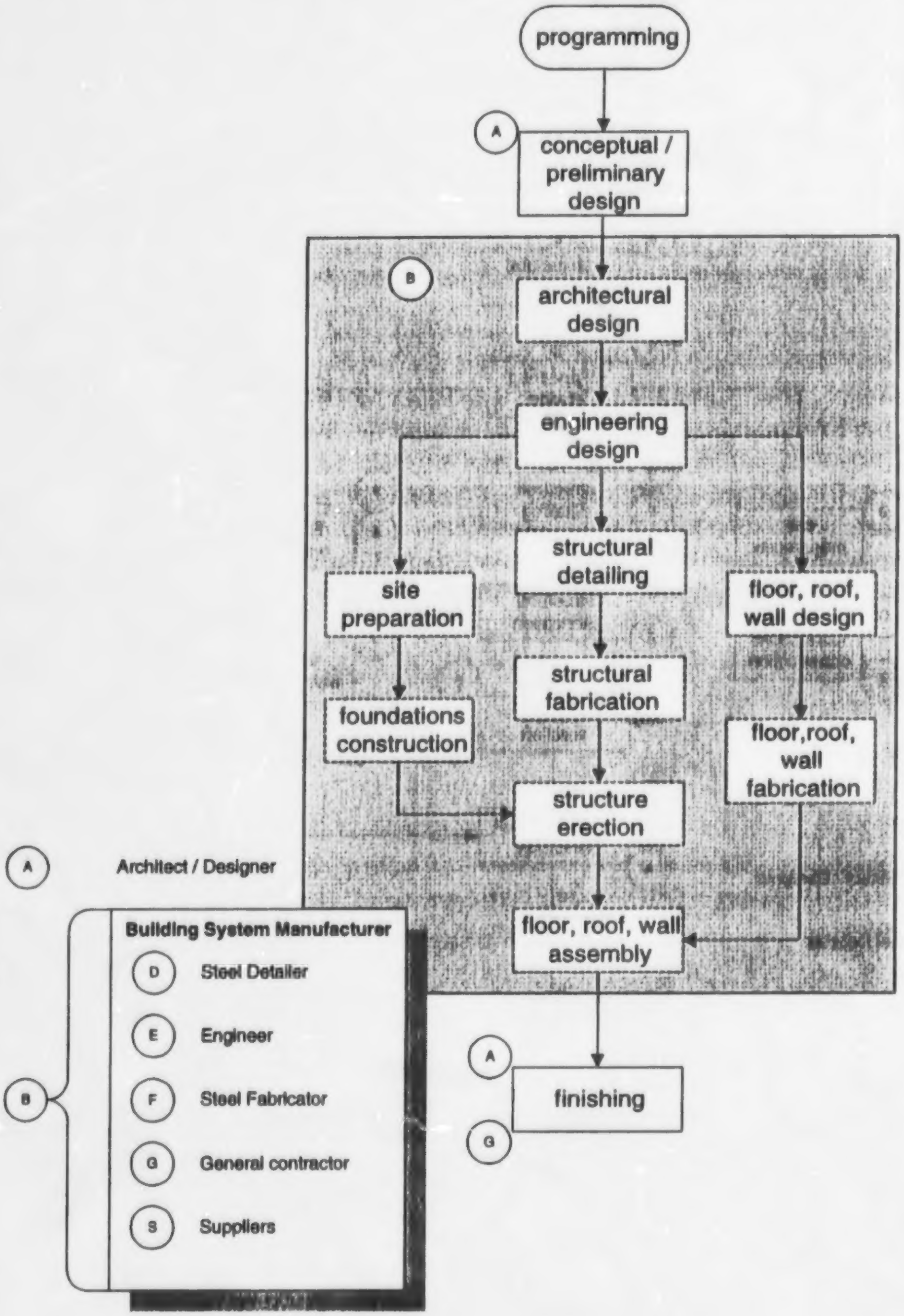


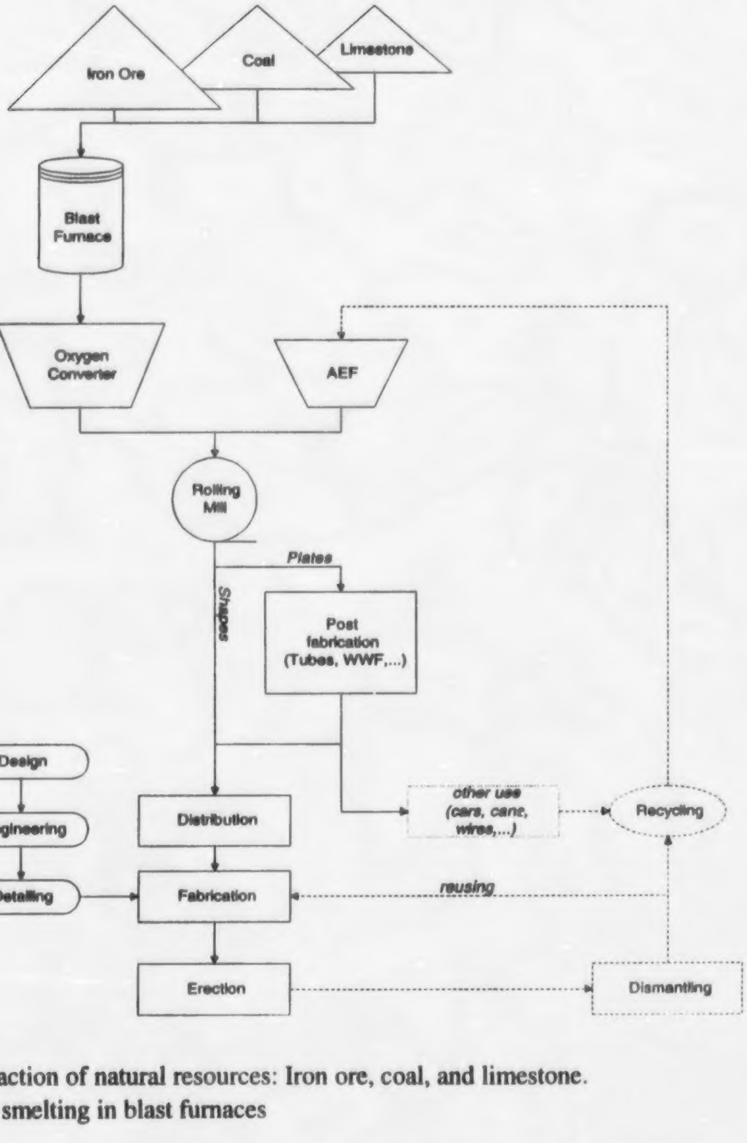
Figure 19: System building process of a steel house



CHAPTER 7 - CANADIAN STEEL SUPPLIERS & TRADES

The application of structural steel to residential construction may rely on the availability of local skills, trades and experience. Canadian steel industry is present at every level of the steel production and fabrication, from the extraction of iron ore to the building of structures. Figure 20 shows the cycle of steel and the various phases leading to the fabrication of structural steel:

Figure 20: The cycle of steel



- Extraction of natural resources: Iron ore, coal, and limestone.
- Iron smelting in blast furnaces

- Steel making from iron and scrap utilizing two different processes: oxygen converter or Electric Arc Furnace.
- Manufacturing in rolling mills of steel structural shapes or plates.
- Transformation of semi-finished products in other structural shapes (Tubes, WWF, ...)
- Warehousing and distribution of structural steel.
- Design and fabrication
- Structure erection.
- Recycling and collection of scrap metal and reuse in integrated mills (28 percent) and minimills (100 percent.)

The following sections identify and analyze in more detail the key industries, businesses, and professionals involved at each phase of the cycle of steel and, when the question is relevant, how their skills could be applied to the construction of steel houses. An explanation on the steel technical terms used in this chapter is provided in Appendix F, *Glossary of Steel Terms*.

Iron ore

The Earth's crust contains an average of about 3.5 percent of iron, which is the fourth largest abundant element, after Oxygen, Silicon, and Aluminum. Iron ores are usually found in the form of iron oxides, such as Hematite (Fe_2O_3) or Magnetite (Fe_3O_4.) China, Brazil, Australia, and Russia are the world's largest iron producers, followed by United States, India, Ukraine, Canada, South Africa, and Venezuela. Canada is amongst the top ten, producing 36 million tonnes of iron ore in 1997, with two-third coming from Newfoundland, one-third from Quebec, and one percent from Ontario.

Table 15: World 20 largest producers of steel in 1997

Country	million t/a
China	107.3
Japan	104.5
United States	99.2
Russia	46.9
Germany	45.0
Korea	42.5
Brazil	26.2
Ukraine	25.5
Italy	25.2
India	23.8
France	19.8
United Kingdom	18.5
Taiwan	15.9
Canada	***15.4***
Mexico	14.3
Turkey	14.2
Spain	13.8
Belgium	10.8
Australia	8.7
South Africa	8.2
World Total	**794.5**

Steel making

The traditional way of making steel consists of processing iron ore, coal, and limestone in a blast furnace to produce hot, liquid iron which is then refined in an oxygen converter to produce liquid steel, which is in turn casts and rolled in steel profiles or intermediary products. Most modern mills combine vertically the process from iron to finish product and are often referred as integrated production. The blast furnace consumes huge amounts of raw material, energy, and water and needs extensive pollution prevention measures to reduce its impact on the environment.

A more recent method melts scrap metal in electric arc furnaces (EAF.) The process, often called minimill, is more efficient and environmentally friendly because it uses recycled steel and electricity rather than iron smelted from raw iron ore and coal. Minimills usually produce new steel from 100 percent recycled steel and the process has very low emissions. Minimills are less capital-intensive than integrated production units, and although originally designed to produce high-grade steel, are increasingly taking over the competitive market of the so-called ordinary steel. (See Chapter 5: SMA.) As a result, last year, all around the world, not a single new blast furnace was built. Half of Canada's steelmaking capacity is based on EAF technology.

In 1997, the world production of steel was approximately 800 million metric tons. Table 15 list the 20 largest world steel producers and their annual production in millions metric tons. Canada ranks #14.

In 1997, the Canadian mills employed about over 33,000 persons and produced approximately 16 million metric tons of steel for total sales of 11.3 billion Dollars. This production consumed 10 million tonnes of coal and 16 millions tons of iron ore. It also recycled 8.5 millions tonnes of scrap metal, which represented approximately 55 percent of the total steel production. This already high percentage of recycled steel is likely to increase in the future, as the EAF technology is increasingly becoming the norm.

In 1997, for the first time in recent history, Canada became a net importer of steel, importing 1 million tonnes more than it was exporting. One of the reasons was the arrival of Russian steel, priced well below market level. In 1998, the Asian economic crisis triggered another price war, with steel products being dumped at low market price by countries such as Korea, Russia, Spain, Turkey, and Argentina. As a result, the prices for wide-flange beams mainly used in construction fell by 20 percent to 30 percent, illustrating the challenge faced by Canadian mills in the global market.

There are 14 steel mills in Canada producing a wide range of products for many different uses: automobile, construction, manufacturing, piping, and wires. (See Appendix E for additional data on the Canadian steel industry.)

Table 16: Product Range of Canadian Mills

Company	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
Algoma Steel Inc. (1)		B	C	D				H										R			U		
Atlas Specialty Steels		B										L	M	N		P							W
Atlas Stainless Steels									I														
Co-Steel Lasco		B								J	K						Q	R					
Dofasco Inc. (1)	A	B	C	D	E	F	G													T			
Gerdau Courtice Steel Inc.		B								J	K	L					Q						
Gerdau MRM Steel Inc.		B								J	K						Q		S				
IPSCO Inc.		B	C					H												T		V	
Ispat Sidbec Inc.		B	C	D						J	K	L			O		Q			T		V	
Ivaco Inc.		B													O								
QIT-Fer et Titane Inc. (2)	A	B																					W
Slater Steels		B								J	K	L											
Stelco Inc (1)		B	C	D	E		G	H		J	K	L			O					T	U	V	W
Sydney Steel Corporation		B																	S				W

Legend

A Pig iron
B Ingots, billets, blooms, slabs

Flat Products
C Hot rolled sheet and strip
D Cold rolled sheet and strip
E Galvanized sheet
F Tin plate (and "tin free")
G Pre-painted steels
H Plate
I Stainless steel plate, sheet and strip

Rod and Bar Products
J Merchant bars
K Concrete reinforcing bars
L Special quality bars
M Stainless steel bars
N Tool steels
O Wire rods
P Cold finished bars, carbon and alloy

Structurals
Q Intermediate structurals
R Heavy structurals
S Rails

Pipe and Tube
T Pipe and tube, welded
U Pipe and tube, seamless
V Hollow structural sections

Other Products
W Company Special Profiles

(1) Algoma, Dofasco and Stelco are integrated mills, with Blast furnace

(2) QIT Fer & Titane produce steel from limenite ore in arc furnace.

Table 16 presents the product range for each company. The bold entries indicate an integrated mill with a blast furnace.

Canadian mills are small relative to world standards. The largest mill in the world is Nippon Steel with 26.4 million tons output per year (1996 Data.) Stelco, the largest Canadian mill is only the 35th in the world with an output of 4.5 million tons (1996) and Dofasco, the second largest in Canada ranks 66th with 2.5 million tons. The largest foreign mills such as Nippon Steel, British Steel, and TradeArbed have all commercial representations in Canada.

Canadian steel companies are strongly integrated into the North American economy. Many factors are contributing to the unification of North American Steel production:

- Same suppliers of raw materials (iron ore, scrap, coal)
- More than half a million Canada-U.S. steel transactions each year made through a network of service centers on both sides of the border.
- Biggest customers spanning national borders (for example, automobile companies)
- Elimination under NAFTA of tariffs on steel products shipped between Canada and the U.S.
- Same union operates on both sides of the border.
- Transborder investments in steel production and finishing facilities.
- Common standards and specifications
- Steel mills in Canada and U.S. border use each other as sources of supply to even out production.

The integration of the North American Steel economy allows US and Canadian companies to better compete in the global market.

Steel profiles manufacturing

The construction industry uses a wide-range of structural steels. The mills produce these steels by a process known as continuous casting, which consists of fabricating sections directly from the liquid metal generated in the oxygen or arc furnace. The resulting product may have the final structural shape ready for use or may enter in the fabrication of other shapes such as tubes or welded beams. Continuous casting is much more efficient than the traditional process of making steel products by rolling billets and slabs, and it is used in almost 100 percent of Canadian production.

Shapes

Mills tends to specialize in various profiles and products (see Table 16.) The products manufactured by steel mills for structural applications are:

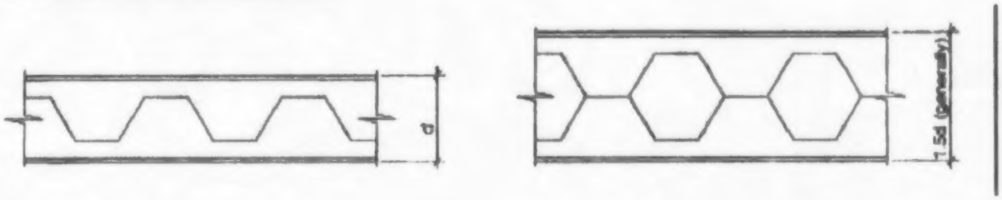
- **Structural shapes** often designated by a letter indicative of the profile such as "I" beams, "C" channels, "L" angles, "T" tees. These profiles are made in the mills by continuous casting and hot rolling.
    - There are various type of "I" beams. The most common profiles are the W Shapes or Wide Flange Beams, designed to optimize their resistance to bending. Other beam shapes are HP shapes, which are square, and light beams such as M shapes, S shapes, SLB super light beams, and B Shapes or bantam beams.
    - C channels have two categories: C shapes or Standard shapes and MC shapes or Miscellaneous shapes.
    - L angles can have equal or unequal legs
    - Tees are usually cut from "I" profiles.

Algoma is the only Canadian mill producing W and H shapes. It encompasses 60 to 70 percent of the Canadian market. Algoma is, however, ceasing production of W shapes by the end of 1999.

- **Tubes,** referred to as HSS for Hollow Structural Sections, are manufactured using either a seamless or welding process.
    - Seamless products are obtained by extrusion.
    - Welded products are manufactured from flat-rolled steel, which is cold-bent and welded.

  HSS may have three different shapes: square, rectangular, round. Traditionally used for columns, they are increasingly applied to make other structural components such as trusses, beams and bracing,
- **Plates** are seldom used as such in structural applications, but enter in the fabrication of other structural shapes as:
    - HSS (structural tubes) described above
    - WWF or Welded Wide Flange Beams made by welding three plates to form an I Beam.
    - Portal frame rafters and columns used in metal building systems.
    - Thin, flat plates used in cold-formed framing.
- **Fabricated products** such as tubes and WWF can be made by the mills or by other specialized plants, or by fabricators. In Canada, the largest non-mill tubes plants are Sonco, Atlas Tubes, Standard Tube of Canada, or Prudential Steel. Eighty-five to ninety percent of HSS used in Canadian construction is produced in Canada. Other fabricated structural products are open web steel joist and castelated beam. The latter consists of cutting a beam web longitudinally in two following a trapezoidal wave pattern. The two pieces are then staggered and welded back to form a much stronger beam of the same weight (see Figure 21.)

Figure 21: Castellated Beam



Grades

The most common grade available today is 350W. The number 350 indicates a minimum yield strength of 350 MPa and the letter W is for weldable. In 1997, Algoma upgraded its entire production of beams from 300W to 350W, which represented a 16.7 percent strength increase- without an increase in cost. The new grade makes possible savings between 3 to 14 percent for short span where strength is the controlling factor and savings of three to five percent for long span where deflection control is more predominant.

The 350 W grade is also normally used for HSS and open web steel joist.

Steel in residential construction

All of the above products can be used in residential construction. However, because of the typically lower design load criteria and shorter span, the design of steel houses usually requires lighter elements than in commercial or industrial construction. Light HSS columns are available in Canada while beams smaller than W150x22 are coming from abroad.

Steel distribution

The wide range of shapes, sizes, and grades requires planning in the manufacturing, stocking, and distribution of structural steel. Steel mills usually produce each structural profile in batch, or rolling schedule, at interval varying from a couple of month to a year, or in some case at demand. For that reason, mills and tube plants seldom sell direct to the fabricators except for large yearly orders, usually greater than 2,000 t/yr. Instead, the products are sent to distribution centers -referred to as service centers- that wholesale or retail them to the fabricators.

Service centers play an important role, particularly in the construction industry, by providing customers with the full range of grades and sizes produced by a number of different steel producers, domestic and foreign, and offering prompt delivery in small quantities when required.

Many service centers are members of the CISC and the SSCI (See Chapter 5.) They are located in every major city and industrial centers in Canada, and via their subsidiaries have access to the North American, as well as, the global market.

Steel fabrication

The function of the steel fabricator consists of pre-fabricating the structure according to the drawings of the engineer. Although a structure may be extremely varied and complex, its pre-fabrication requires only a few rather simple operations, such as, cutting, shearing, welding, punching, drilling, and bending. Fabricators have access to a wide range of steel products, profiles, tubes, bars, and plates purchased from service centers or mills. They fabricate a large variety of structural elements for buildings, bridges, industrial equipment, or architectural decorative purposes. These elements and their connections are usually designed and fabricated in sizes and configurations convenient for handling, shipping, and site assembly. Despite the apparent simplicity of the basic shop operations, steel fabrication requires special skills and knowledge because the required precision of structural members and connections, and the quality of welding. Most projects require the fabricators to be certified by the Canadian Welding Bureau (see Chapter 6.) Today, large to medium-size fabricators can offer a full structural steel, and sometimes mechanical, service including conceptual and detailed design, fabrication, shipping, construction management, and erection. The largest companies employ engineers, draftsmen, and detailers in addition to the traditional shop workforce.

Fabricators may be involved in building construction in three different ways:

- Conventional: designed by an outside architect / engineer, and constructed by a general contractor with steel elements provided by the steel fabricator
- Design-built: The building is designed and constructed by a single entity that includes both the designer and the steel fabricator.
- Pre-engineered: A local fabricator or builder acting as a dealer for a metal building manufacturer, which is often a US company, contracts with the owner, who may or may not be assisted by an architect.

Industry profile

Industry Canada (IC) provides economic data on the steel fabrication industry using the industrial classification system of Statistics Canada usually referred as the Standard Industrial Classification Code (SIC):

"The highest level of SIC categorization (Statistics Canada refers to these as divisions) is by industrial activity: Manufacturing, services, natural resources, wholesaling or retailing. Within these broad divisions, three more levels of categorization are performed, each becoming more

precise. Statistics Canada describes these as 2-digit SICs, 3-digit SICs and 4-digit SICs. Industry Canada (IC) uses the SIC code at the lowest or more precise level to provide detailed economic and business information on Canadian industrial activities." (Source IC)

IC estimates than in 1996, the sector SIC 302 (Fabricated Structural Metal Products Industry) produced $2.7 billion in shipment.

Two sectors from the Fabricated Structural Metal industry of particular interest in relation to the use of structural steel in housing are "*Pre-Engineered Metal Building Industry, except portable,*" (SIC 3023) and "*Other Fabricated Structural Metal Products Industry*" (SIC 3029.) Although, presently few fabricators of these categories ever produce steel houses, they both have the capacity and technology to fabricate system building and structural components adapted to housing.

Pre-engineered metal building industry

The main products related to this industrial sector include:

- Metal aircraft hangars.
- Metal garages.
- Metal office and factory buildings.
- Pre-engineered metal buildings.

In 1996, the pre-engineered metal buildings industry accounted for 14.1 percent of the total structural sector, produced $400 millions in shipment and employed less than two thousand people. Employment has decreased over the last 6 years by 1.4 percent a year, while it has increased by 3.3 percent in US during the same period. The productivity, or value of shipment per employee, in 1996 was $200,000. The cost of material, steel, supplies, components used in the fabrication was approximately $200 millions, or 50 percent of shipment value. In 1996, the sector ran a trade surplus of $112 millions, principally with Japan and USA.

IC estimates that there were 49 manufacturers of pre-engineered metal building in Canada: 80 percent of the plants are located in Quebec, Ontario, and Alberta, and the rest in B.C., Manitoba, and Saskatchewan. Most companies are small to medium businesses having between 20 and 100 employees. Appendix G presents a list of Canadian metal building system builder, according to the statistics of Industry Canada

Other fabricated structural metal products

The main products from this sector include:

- Bar joists or open-web steel joists.
- Prefabricated bridges
- Metal forms for concrete construction
- Fabricated structural shapes (such as open web steel joist or WWF beams)
- Prefabricated structure.

In 1996, output from this sector accounted for 56.5 percent of the total structural sector, producing approximately $1.5 billion in shipment with about 7200 workers and 2000 administration staff, for a total employment of 9200. The statistics shows that employment in the sector declined by 30 percent from 13,000 employees in 1990, or 5.6 percent per year. During the same period, the employment in US decreased by 2.3 percent per year. The productivity was $180,000. The cost of material, steel, supplies, and component used in the fabrication was approximately $700 million, or 50 percent of the total shipment value. In 1996, the sector ran a trade surplus of $108 million mostly with USA.

Table H-1 in Appendix H contains a list of Canadian steel fabricators, obtained by combining the list of CISC's members and IC's list of major players of the sector *"Other fabricated Structural Metal Products Industry"* (SIC-3029.) IC estimates that 246 fabricators operated in 1997. Table H-1 has only 202 entries and therefore may not contain all existing Canadian establishments. The sample is, however, large enough to give a profile representative of the fabricator industry. Table H-4 present a distribution of fabricator by Province and by size. It indicates that steel fabricators are in general relatively small companies. Almost 75 percent of the companies have less than 50 employees and half of them employ between 20 and 49 employees. (See Fig 22.) Only one company employs more than 500 workers in a single plant.

Figure 22: Size of Steel Fabricators

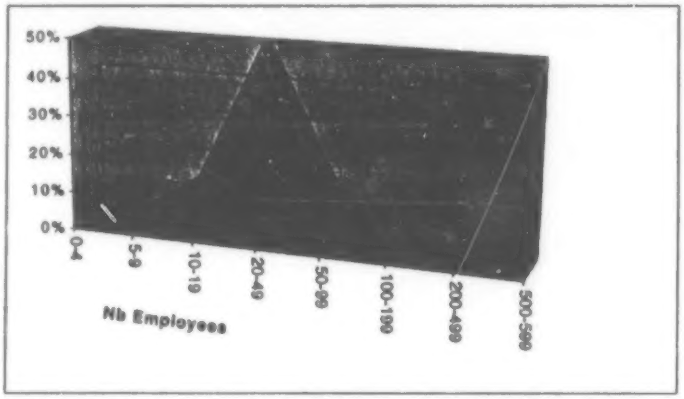


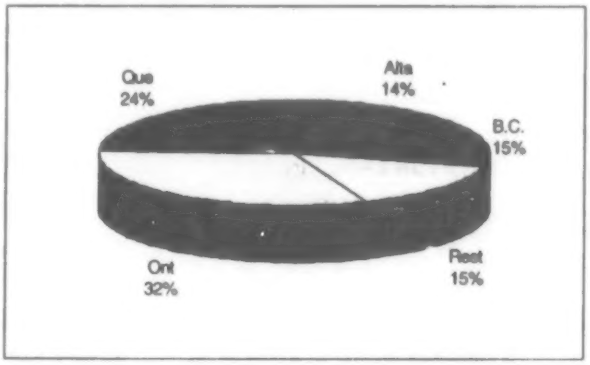
Figure 23 shows the distribution of companies by regions. The location of industries seems to match the distribution of the Canadian economy. One-third of all fabricators operate in Ontario and one quarter operate in Quebec. B.C and Alberta have approximately 15 percent each. The rest of Canada shares the remaining 15 percent. Table H-5 in Appendix H presents a distribution by type of product: structures, joist, and plates. It shows that 90 percent of Canadian companies fabricates structures amongst other products and 45 percent make only structural steel.

Industry Canada estimates that 65 percent of steel fabrication is for building construction. Therefore, it can be estimated that the total production of Canadian structural steel for building construction is approximately $1.5 Billion x 90% x 65% = $0.87 Billion.

Steel fabrication for residential construction

The fabrication of structural steel for houses is not significantly different from other structural applications. The basic operations of cutting, drilling and welding remain the same. Steel structures for housing require, however, lighter members and need ten times less steel than a small commercial project. Nevertheless, a phone survey of fabricators in Vancouver revealed that most of them would consider any kind of job of any size. Some companies did build steel houses but these were special projects for the high end of the housing market. One fabricator was simultaneously working on a large project in the US and fabricating small architectural artworks. However, large fabricators would prefer to work on large projects whenever possible and leave the small job to smaller companies.

Figure 23: Distribution of fabricators by regions



Steel Assembly

The site assembly of a prefabricated structure is in most cases fast and straightforward. The steel erectors may be independent contractors but often, as explained before, it is the steel fabricator that provides the erection services. IC does not distinguish between fabricators and erectors and it includes the latter in the general sector "*Other Fabricated Structural Metal Products*"

A steel structure is usually bolted, and sometimes welded. The erection requires little special equipment besides a crane, which is usually sub-contracted. Despite the apparent simplicity of the construction process, steel erectors require special skill and knowledge, particularly in relation to assembly procedures, planning, and safety. To illustrate the kind of expertise required by steel erectors, hereafter follows an excerpt of the certification program proposed by the AISC, in US.

"The basic certification includes:

- *Written erection stability plan*
- *Formal safety plan*
- *Program in-place to promote project planning*
- *Formal program to monitor compliance with welding and bolting procedures*
- *Written substance abuse plan and policy*

In addition, the advanced certification includes:

- *Experience in retrofit and maintenance*
- *Experience with complex projects such as working over water and railroad tracks*
- *Experience with large scale erection projects*
- *Experience and equipment for rivet removal*
- *Written procedure for jacking and use of false work "*

Assembly of a steel house

The structural assembly of a steel house is basically the same as for any other structure, except that the quantity and size of steel is smaller. For example, the erection of a steel house in Surrey (See Chapter 4) was completed in one day by two steel erectors with a crane. On the second day, the two erectors completed the adjustment, bolting and snug tightening of the structure.

Steel Design

Building with structural steel involves three categories of design professionals:

- Architects,
- Engineers.
- Steel detailers.

Architects

The architect provides consulting services for the design and construction of the building. He plays an important role in selecting the material and the technology, basing his decision on multiple factors such as the needs of the client, the building program, costs, site, and aesthetics. When designing a building with structural steel, he is responsible for translating the owner's intended function and for providing to the structural engineer sufficient information for designing the structure.

The Canadian architectural services industry comprises approximately 3,500 private firms, which employ 11,500 workers and 7,700 registered architects. The services of architects are required by law in all provinces for the design and construction of multi-unit residential buildings and building housing public gatherings for commercial, institutional or cultural purposes.

Architectural design of a steel house.

The services of an architect are not required for designing and building a single-family house. However, there are many examples showing that houses designed by architects are more economical to build and answer better to users' needs. Steel houses emphasize design and planning which require the input of an architect.

Engineers

The NBC requires that a professional engineer (P.Eng.) supervises the design and construction of a structural steel (see Chapter 6.) In Canada, there are 160,000 engineers registered as members of local associations. (See Chapter 5.)

Consulting engineers

Engineers who provide design services for capital projects, such as building, are called consulting engineers. IC estimated that, in 1995, there were 6000 consulting engineering companies in Canada employing 70,000 persons firms and generating $6 billions in direct revenue. The most important source of revenue was design services, which represented 45.7 percent of the total with services related to building accounted for 13 percent of the revenue. Therefore, the design of building generated a revenue of $6 billion x 45.7% x 13 % = $356 millions.

Most consulting engineers are members of the ACEC (See Chapter 6.)

Increasingly consulting engineering companies provide comprehensive turnkey services such as:

- **MEPC:** Management Engineering Procurement Construct projects, which involve the packaging of engineering services, as well as, procurement, equipment supply, and construction services.
- **BOOT:** Build Own Operate and Transfer where the project bidder agrees to finance, build and operate the facility until the costs are fully recovered.

Because steel houses put the emphasis on design and planning, a consulting engineer company could successfully apply MEPC or BOOT methods to the residential market and join forces with a steel fabricator for producing low-cost housing systems.

Structural engineers

Usually, the professional association requires the engineer to have a specialization and experience in structural engineering for designing structures. The structural engineer of record (SER) has the responsibility to design the primary (or main) structural system but not the secondary elements such as curtain walls or claddings. (See Chapter 6.) Nowadays, the SER uses one of the many structural analysis software available on the market to design, calculate and evaluate the most complex structures. These programs are increasingly being integrated with other programs that are related to the detailing and the fabrication of the structure. However, the SER is not responsible for designing steel connections which falls under the responsibility of the specialty structural engineers. The latter may be a consulting engineer working with the detailer or an employee of the fabricator.

Engineering design of a steel house

As discussed in Chapter 6, an engineer must supervise the design of the structural steel even for single-family residential construction. The cost increase resulting from engineering fee can be greatly mitigated when the engineer teams up at the early design stage and by using computer, integrates his work with the construction process.

Detailers

The role of the detailer is to produce shop drawings starting from the SER design. The detailer does not design the structure but provides detailed instructions on how to fabricate and erect the components. Shop drawings include erection drawings, welding specifications, connection details, and bill of materials. (see Chapter 6.) The detailer is not responsible for the calculation and sizing of welding and connections that are under the responsibility of the specialty structural engineer. Some fabricators or large engineering company may have detailers on staff but the trend in Canada is to use the services of independent contractors. Some detailing companies may be quite large with more than 50 draftspersons. Detailing is currently a non-chartered activity but that may change as some of the large detailing companies are creating a certification process via local associations such as the SDIBC in B.C.

Conclusion

The Canadian steel industry is highly value-added, generating billions of dollars in sales, providing thousands of jobs, both direct and indirect. The industry is active at every phase of the steel production and fabrication, and it is present in every province. The production of Canadian steel is becoming an increasingly cheaper, cleaner, and more sustainable process because of EAF technology together with the use of recycled steel replaces the traditional resources and energy-consuming blast furnaces. The North American steel economy industry is strongly integrated, and as a result, Canadian companies have free access to the US market both for purchasing materials and for selling their products. Through this unified market, there is a wide range of structural profiles available for building steel houses.

There are about 250 steel fabricators distributed in every region of Canada. The majority are medium-sized and have less than 50 employees. Overall, they have the capability of fabricating and building steel houses without any significant technology change. The trend in the steel construction industry is to provide fully design-built services, including conceptual and detailed design, fabrication, and erection.

Building with steel requires the services of structural engineers and detailers and in most cases, may need the input of architects. There is a wide availability of these professionals across Canada. Nowadays, consulting engineers often provide turnkey services including financing, design, and construction. This formula could be easily adapted to the construction and supply of steel houses.

CHAPTER 8 - CONSTRUCTION SYSTEM

This chapter presents the design of a steel house that could be used as a prototype to demonstrate the advantages of building with steel.

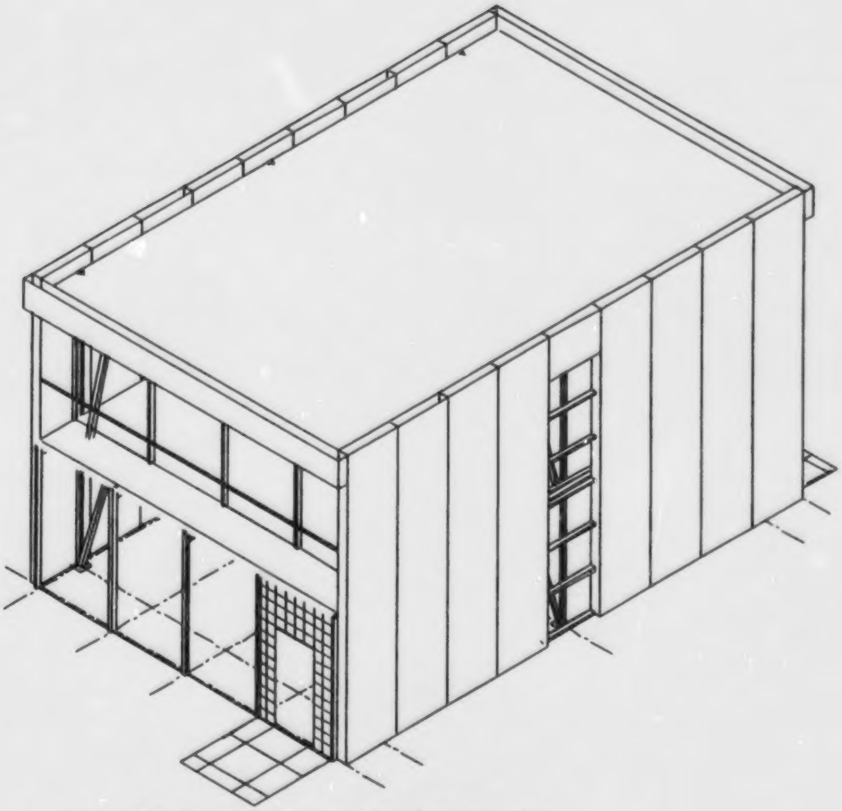
As mentioned in the previous chapters, the main characteristics of a steel house are:

- the application of the technology of metal building system to single-family residential construction.
- the use of a structural steel system distinct from the envelope.
- the prefabrication of most components.

Design criteria

The objective of this prototype is to provide an affordable solution to urban and suburban single-family housing. The design criteria includes:

Figure 24: Prototype steel house



- low cost compared to conventional construction
- simplicity and flexibility
- flexible space adaptable to varying usage

- prefabrication, ease, and speed of assembly
- structural, fire, and seismic safety
- low operation and maintenance cost
- exportable

Figure 24 gives a tree-dimensional view of the prototype. The house has a simple shape and responds to the following criteria:

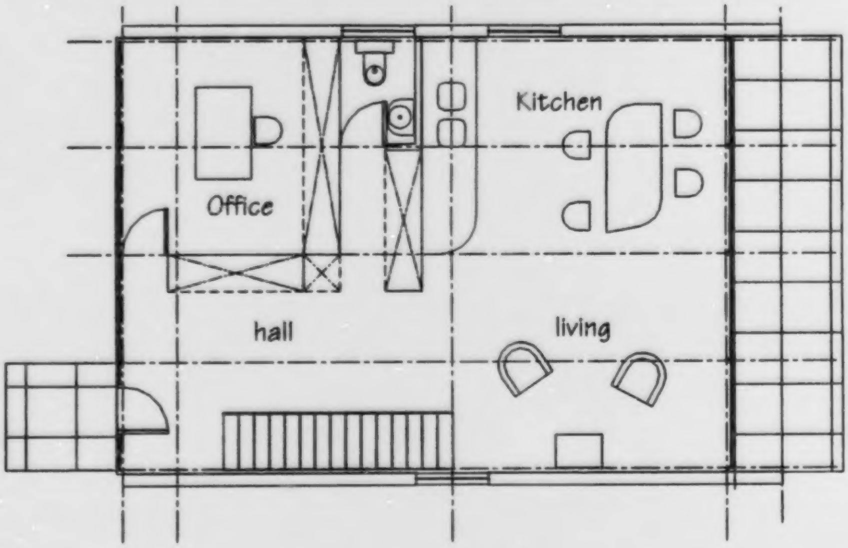
Program

The prototype is designed for a single-family of four people but can also be subdivided in two urban flats. The house has high ceilings that offer greater flexibility for future usage and open lofty space that can be proposed as "artist studios".

Setting

A typical setting for this prototype would be a city lot where high land costs require the optimization of space resources. A standard lot in the city of Vancouver has a width of 33' wide and a depth varying to a maximum of 120'. Local fire code requires a minimum offset of 4' (1.2 m) from the property line. Therefore, the width of the house is 25' (33'–2x4'= 25') or 7.62 m. If the zoning regulations permit it, the design can be changed into a townhouse because most of the building materials are non-combustible.

Figure 25: Prototype house, main floor



Layout

The building has a simple rectangular shape of 10.97 m long by 7.62 m wide by 6.09 m high (36 'x 25' x 10'). It offers 167.22 m2 (1800 ft2) of living space on two floors, which can be subdivided into two 83.61 m2 (900 ft2) studios. The distance between floors is 3 m (10'.)

The flat roof is simple and efficient. It allows to gain maximum height while complying with local height restrictions.

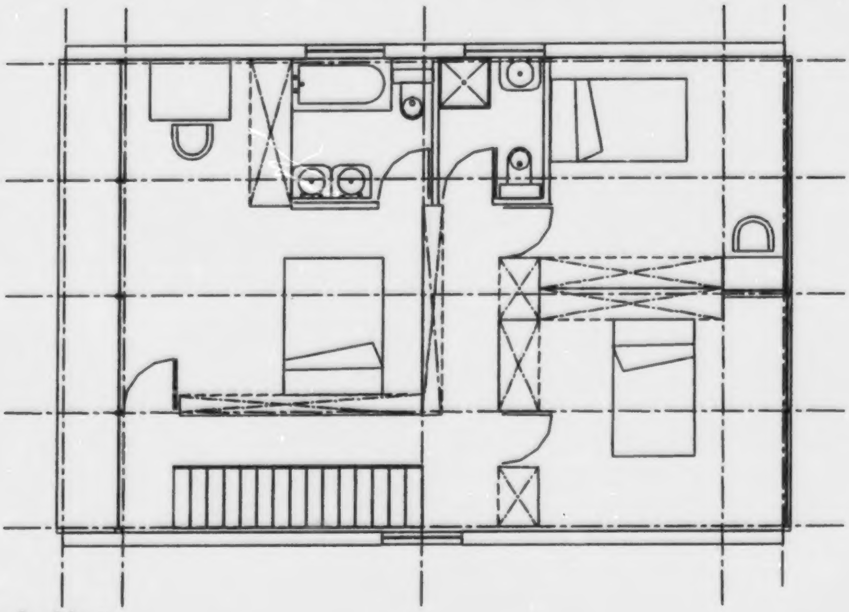
Flexibility

The design allows maximum flexibility. The basic house has two empty, open floors that the owner may finish himself.

The structural system is autonomous and leaves the interior free of columns or bearing walls. The structure also provides lateral stability, requiring no shear walls or cross bracing, freeing the external walls of any bracing constraints.

Therefore, the layout can be left completely open or subdivided with light partitions or pre-manufactured cabinets.

Figure 26: Prototype house, upper floor.



Each floor may also become an independent studio. Consecutive users may adapt the layout to their particular needs. For example, the space facing the street may become an home office, garage, workshop, or living room.

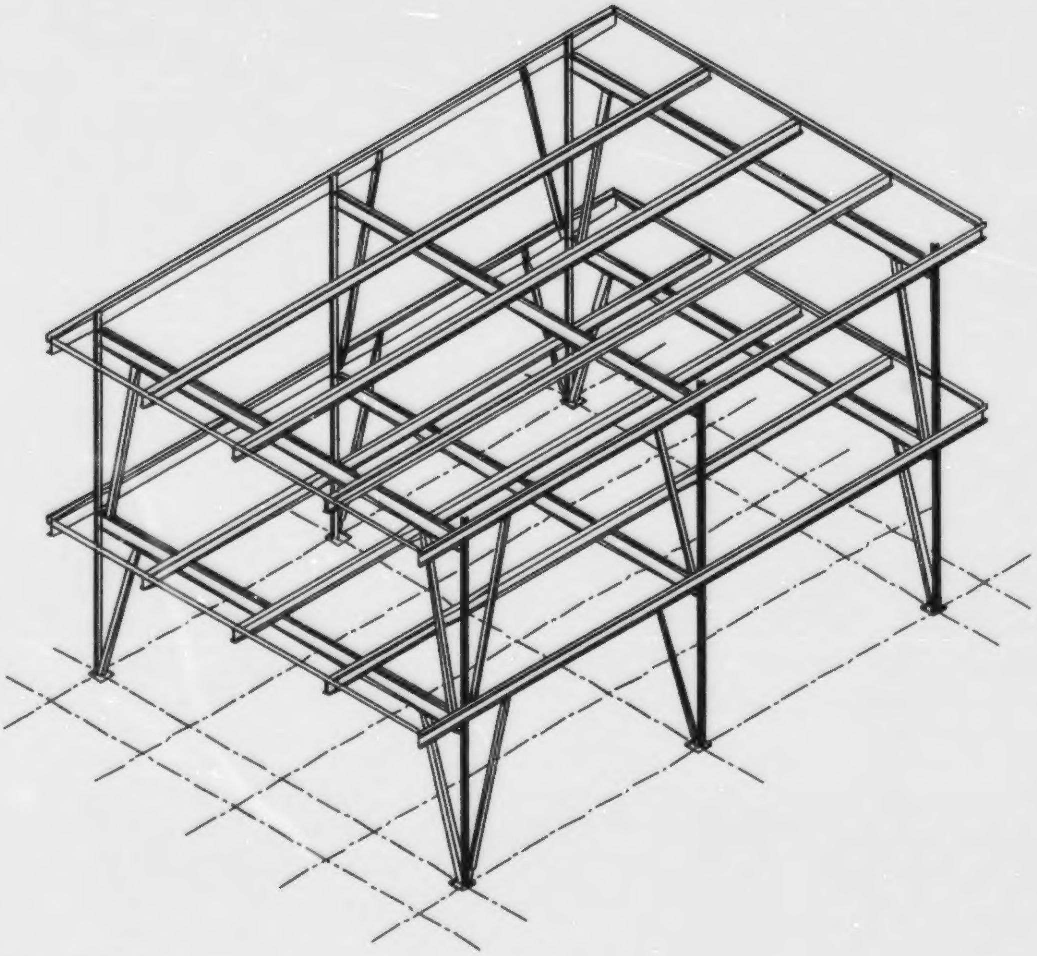
Figures 25 and 26 show the plans for a three-bedroom house with two bathrooms, a kitchen-living room, and a home office near the street entrance. All the partitions are made with pre-fabricated cabinets.

In compliance to the fire code, the side walls are made with pre-fabricated panels and have few openings. The front and back walls are made with glass panels to take maximum advantage of natural lighting and solar energy. Plain panels or doors can replace these panels if necessary. The flat roof may support a roof garden, which is becoming an essential and popular feature of urban living. Roof gardens increase the thermal efficiency of the building. The flat roof provides also the flexibility for future vertical extension.

Simplicity

The intent is to propose a basic building as simple as possible, adaptable to the need and taste of the occupants. The steel is left exposed but can be covered with drywall if required. The floor, made with polished concrete, can also be left exposed or covered with carpet or other flooring material. The simple rectangular floor plan allows for a multitude of uses, as well as, optimization of the lot.

Figure 27: Prototype house: Steel structure.



Affordability

The objective is also to provide low-cost affordable urban housing. Costs are reduced by simplicity of design, do-it yourself, exposed material, prefabrication, fast assembly, and the use of steel.

Exportability

All the elements can be shipped in a container and exported.

System building

The prototype is a building system that integrates architectural, structural and energy requirements. The entire design process can be streamlined by computer programs. The same company can design, fabricate, and assemble all the components. However, a professional engineer is still needed to coordinate the structural design, and to review the field work. In addition, some sites may require a geotechnical investigation.

Structural steel frame

Model

The structure is self-standing and independent of other elements of the building. Figure 27 show a three-dimensional view of the main structural steel system..

The structure has three components:

- three rigid frames (or portals) supporting the first floor and the roof
- five continuous steel joists that span over the length of the building
- two continuous steel decks supported by the joists and covered with concrete.

The structure is self-standing. The "K" bracing system is designed to resist seismic and wind-generated lateral loads. Consequently, the building does not require any shearing wall or additional cross bracing. The floor and flat roof provide the horizontal bracing system.

The loads follow the requirements of the province of BC Building code ed. 1995. The determination of live loads allows for maximum flexibility and interchangeability between the floors, as well as, the use of the roof for a roof garden

Table 17 presents the design climatic data, design loads and deflection criteria for Vancouver, B.C.

A computer program calculated the forces, moments and displacements of each element of the structure for each load case combination specified by the building code: Dead, live, snow, wind, and seismic. (See Appendix I)

Detailed design drawings

The drawings in Appendix J illustrate the structure design and the connection, while the dimension, size, and weight structural elements are listed in Appendix K.

- The main structural component is a rigid frame with a W250 horizontal beam (B), two oblique square HSS (X), and two vertical double-angle struts (C). The central portal has heavier elements because it receives greater forces. The W beams and perimeter channels are bolted directly to the double-angle struts without the need of connection plates.
- K bracing made with HSS 64x64 elements (Y) provides for the longitudinal stability.

Note: The plans and drawings included in this report are preliminary and for reference only. They must not be used for construction.

Table 17: Climatic data, design loads, and deflection criteria

		Unit	
Climatic Data			
Ground Snow load	2.2	kPa	(1)
Rain in Snow	0.3	kPa	
Hourly wind Pressures 1/10	0.46	kPa	
Hourly wind Pressures 1/30	0.58	kPa	
Hourly wind Pressures 1/100	0.72	kPa	
Seismic data Za	4		(2)
Seismic data Zv	4		
Zonal Velocity ratio v	0.2		
Loads			
Live Load	1.9	kPa	(3)
Dead Load Floor & Roof	2.34	kPa	(4)
Deflections			
Maximum Vertical Deflection	1:360		(5)
Interstorey deflection	0.02 x Hs /R	mm	(6)

	Comments
(1)	Vancouver data
(2)	Vancouver is one of the highest seismic zone in Canada
(3)	Same for main and upper floor for flexibility
(4)	Same construction for floor and roof
(5)	Table A1: Commentary A of Part 4 and NBC 1995 Part 9
(6)	NBC 4.1.9.2. (R=3.5, Hs = 3,048)

Table 18: List of steel elements

Qty	Length m					weight
Size SI	3.6	6.1	7.0	11.0	Total	kg
2xL64x64x6.4		6			6	440
C200x17				4	4	748
HSS64x64x6.4	8				8	305
HSS76x76x6.4	8				8	377
HSS89x89x6.4	4				4	225
L89x64x4.8			4	4	8	397
W200x15				6	6	990
W250x22			4		4	616
W250x33			2		2	462
clip plates						125
Total	20	6	10	14	50	4,686

- Continuous W200 beams form the secondary structural system or joists (J) that supports the steel decks. The perimeter joists are made with C200 channels (S).
- L89x64 angles (L & LS) are attached the perimeter of the floor and the roof. They have the double purpose of retaining the concrete and attaching it to the curtain walls.
- The base plates are welded to the bottom of HSS oblique columns together with plates that connect to the double angle struts and longitudinal bracing.

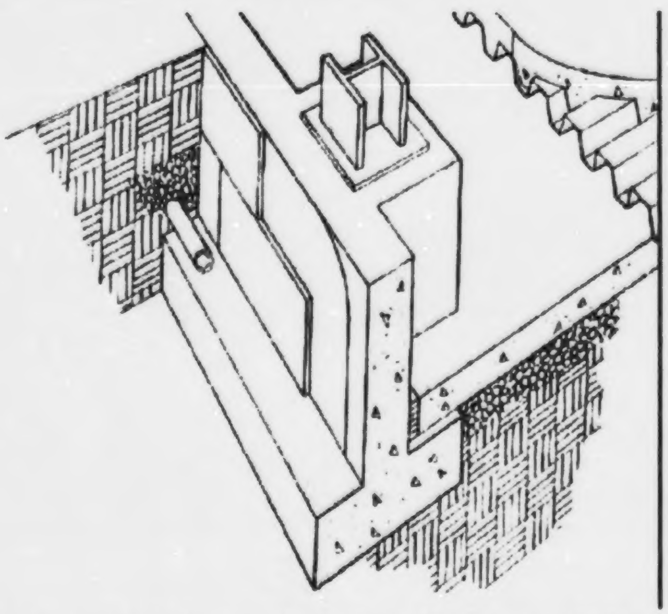
The structure uses only nine different shapes with a total of 50 elements. The total weight is approximately 4,700 kg, including the clip plates.

Construction elements

Foundations

Under each steel column is a 0.30 m (12") diameter cylindrical concrete pier on a square footing. Appendix I shows the calculated reactions of each column. The dimensioning of the footings conservatively estimates an allowable bearing pressure of the soil of 100 kPa. Under this assumption, the dimensions of the footing are 1000 mm x 1000 mm x 200 mm (thick) (40"x40"x8") at the outer portals and 1375 mm x1375 mm x 250 mm (54" x54" x 10") at the central portal. These dimensions may, however, vary according to the type of soils and should be treated as first approximations.

Figure 28: Foundations typical



The concrete has a strength of 28 MPa and has #4 steel reinforcing bars (rebar). Because the rigid frame produces two equal horizontal reactions acting in the opposite direction, #5 epoxy coated rebar embedded in the concrete floor connect the top of the pier foundations.

A wall foundation located at the perimeter supports the external walls and the slab on grade, and provides an additional protection against frost and moisture. (See typical drawing in Figure 28.)

Walls

The walls are made with non-load bearing, light, pre-fabricated panels and windows that are attached to the structure. The walls, as well as the roof elements, completely envelop the structure, eliminating any thermal bridge. The erection of sandwich panel is fast and straightforward. The panels can be installed in one piece over the 6 m (20') height of the building, which is the option chosen in this prototype. The panels are connected to the perimeter angles (L in Figure J-5 – Appendix J). Panel joints are an important consideration because the seams are the weak link of the envelope and the most prone to leakage and loss of insulation.

The wall panels can use different types of technology:

Sandwich panels

These are composite panels made with a solid foam core injected between two face sheets. The resulting sandwich panel acts as a "stressed skin" system and offer considerable resistance to bending.

The insulation foam can be made with polystyrene, polyurethane, polyisocyanurate, or rockwool, each material having different thermal and structural properties. Polyisocyanurate has the highest thermal performance but produces toxic fumes when burning. Table 19 presents the thermal resistance value for the different material discussed in the section.

Table 19: Panels Insulating values and cost

Thermal	*Imp*			Metric			Cost	
Resistance	*R 1"*	*In.*	*R*	RSI	mm		$/m2	$/RSI
Foam Concrete	*1.7*	*8*	*14*	0.30	200	2.40	24	10.00
Polystyrene	*4.2*	*6*	*25*	0.73	150	4.41	43	9.76
Isocyanurate	*7.5*	*4*	*30*	1.32	100	5.28	54	10.19

The face sheets can be made with oriented-stranded boards (OSB) or galvanized steel.

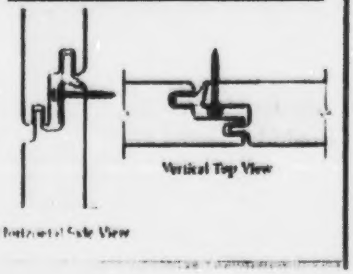
OSB panels are heavier but offer the advantage of offering a nailing surface. They are generally joined by a spline board inserted in grooves cut through the foam core. They can be finished by conventional methods that include vapor and moisture barriers, drywall, and external weather protectors.

Steel panels are becoming increasingly popular in building systems and are worth considering in residential construction. They offer many advantages over OSB:

- they weight less than half of the OSB,
- can be easily attached to the steel structure with special bolts,
- can be fabricated in any length,
- have pre-finished inside and outside surface that may not require any additional finishing work.

Steel panels are usually joined by tongue and groove or concealed fasteners. They can be installed in one piece vertically (6 m height) or horizontally (11 m). (See typical connection in Figure 29.) Horizontal panels offer several advantages such as having joints with a positive drainage and allowing the installation of large or ribbon windows.

Figure 29: Wall panels. connection detail



The panels may contain empty channels for installing electrical wiring and other services. Typical cost for sandwich panels varies from $43/m2 to $65/m2 ($4 to $6 per ft2).

Foam concrete panels.

Foam or aerated concrete is created by the inclusion of air bubbles in a cement-based mixture. This method can produce concrete with a density as low as 300 kg/m3 or eight times less than normal concrete. Aerated concrete has a better thermal resistance than standard concrete, although lower than plastic foams (See Table 19). A 200 mm thick panel achieve an RSI of 2.40, while a 100 mm isocyanurate panel can achieve more than two times this value. Foam concrete needs an additional insulation on the outside to achieve a thermal performance similar to isocyanurate. Foam concrete has also a lower strength than standard concrete. For example, a 400 kg/m3 concrete has a compressive strength of 2 MPa; 15 to 20 times less than normal concrete. This strength may not be sufficient for a bearing wall application but is acceptable for non-bearing curtain panels attached to the steel structure.

Aerated concrete panels can be pre-fabricated in factory and shipped to the site or cast on site and tilted-up. There may be different types of reinforcement such as rebar, welded wire fabric (WWF), or steel studs. Similar to the sandwich panels in the previous section, some of the aerated concrete panels may have embedded channels acting as conduit for electrical services.

Foam concrete is an economical solution for a stable, incombustible, and durable curtain wall system. The panels are thicker because of a relatively low thermal and structural performance; as a result, they are heavier. A panel of 6 m x 1.2 m x 20 cm (20'x4'x8") made with 400 kg/m3 concrete weight more than 600 kg and require the use of a crane during installation.

Estimated cost for foam concrete panels 200 mm thick (8") are $24/m2 (2.20/ft2).

Steel studs

The walls can be made with light non-bearing steel studs and attached to the steel structure. This was the solution chosen for the steel house in Surrey (See Chapter 4). The walls may be assembled on site with steel studs shipped pre-cut by the manufacturer. This solution is, however, labour intensive because it requires many manipulations to install the fiberglass insulation, the vapor, the moisture barriers, and the outside and inside panels and finish.

Alternatively, the complete walls may be pre-assembled. With this option, a factory will manufacture a complete wall containing all the elements: drywall, insulation, outside finish, windows, and electrical wiring. This solution was successfully implemented in Sweden as an answer to the challenge of construction during the winter.

Roof

The flat roof is made of a steel deck supported by a steel joist (J). The built up may vary according to the functions described previously: roof, garden, patio, or vertical extension of the building. The available techniques are:

Built-up

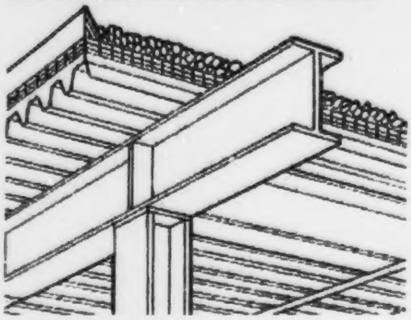
Built-up roofing consist of an insulation and waterproofing system.

The insulation system uses rigid boards of isocyanurate (iso panels) installed directly on the steel deck and attached by adhesives or fasteners. Tapered rigid insulation boards can be added to provide positive drainage.

Waterproofing is provided by membrane of EPDM membrane roof laid on the insulation and attached by adhesives, fasteners, or ballast. (See typical installation in Figure 30.) For a light patio, a wood deck or concrete tiles can replace the ballast.

Light Concrete

Figure 30: Built-up roof - typical



The steel deck receives directly a layer of foam concrete, with a thickness governed by the thermal requirements. Table 20 indicates the design characteristics of the light concrete roof for a RSI value of 5.28 (Imperial R = 30). The concrete would have a thickness of 270 mm (10.5") and exert a load of 0.81 kPa, which is well inferior to the design dead load of the roof. The roof covering uses an EPDM membrane laid on the concrete and attached by adhesive or ballast. The roof can then accommodate a wood or concrete patio or a roof garden.

Floors

The main floor is a concrete slab on grade and a continuous steel deck supports of the upper floor. The slab on grade floor consists of compacted subgrade, gravel of crushed stone or concrete subbase, usually 150 to 300 mm thick (6" to 12"), a layer of fine gravel or sand, styrofoam insulation, vapor barrier, and the slab itself with joints, reinforcing, and finish. The concrete may include a radiant heat water pipe system and electrical conduits.

The steel deck is 0.76 mm (gauge 22) galvanized steel sheet with flutes of 38.1 mm deep (1.5") spaced at 152 mm (6") center to center. The specifications are similar to Canam P-3615. Continuous sheets are installed and tack-welded on the steel joists. The span between joist is 1,905 mm (6'-3").

Table 20: Characteristics of light concrete roof

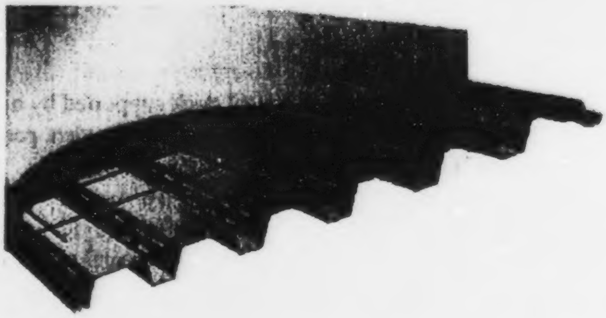
Foam concrete density	300	kg/m3
Thermal resistance	0.010	RSI /mm
RSI	5.28	30 R
Required Thickness	272.10	mm
Weight kg/m2	81.63	kg/m2
Weight kPa	0.81	kPa
Roof Design dead load	1.82	kPa

The floor can finished by two different methods: a concrete slab or a drywall decking.

Composite deck

Structural steel and concrete floors are complementary. The most common method is to lay a steel deck on the steel beams and joists. The deck acts as a form for the concrete floor eliminating the need for temporary support, forms, and shoring. The result is a composite structural system, which puts in compression the top concrete slab and in tension the steel deck and beams. (See Figure 31) Because concrete works best in compression and steel in tension, the net effect of this arrangement is an efficient and rigid floor system. Beside its structural properties, concrete offers many other advantages:

Figure 31: Composite deck



- low cost and ease of installation
- superior sound-proofing, as a result of increase in mass
- fire resistance, due to the property of concrete
- greater thermal mass, resulting in warmer house in the winter and cooler in the summer (see heating)
- The possibility to embed radiant heat pipes as well as other conduits.

The typical thickness of the slab, including the deck flutes, is 100 mm (4"). Table L-1 in Appendix L presents the loads calculations according to the manual of one steel deck manufacturer (Canam).

Drywall decking.

Three sheets of drywall are installed directly on the deck. The floor can get any finish such as carpets or tiles. This option offers a lighter and more economical alternative to concrete although it makes more difficult the installation of radiant heating system and has a lower thermal mass. Drywall decking has been in use for many years in Sweden, Denmark, and other Northern European countries.

Table L-2 in appendix L provides the load calculations for a steel deck covered with drywall according to Canam manual.

Windows

A steel house can use any type of residential or commercial window system. This prototype house uses three window systems: (See Figure 24.)

- curtain glass walls covering the entire front and back walls
- small windows attached to the side walls
- vertical ribbon window in the side wall.

Curtain glass walls consist of metal support, usually aluminum, holding glass panel. They are attached directly to the floor and the roof edges. Curtain walls are a good complement to steel houses, because they can be pre-engineered and assembled quickly. Aluminum curtain walls, however, are more costly than standard residential windows. A more economical option is to attach vertical steel profiles to the structure and to glue glass panels to the profiles using structural silicone adhesives.

Small windows can be installed on site by cutting an opening in the sandwich panel and screwing a window unit on the external side of the wall, as in conventional construction. A more efficient option is to pre-install the windows during the manufacturing of the panel.

Ribbon windows can be made by replacing wall panels with glass panels. In this prototype, a vertical ribbon window replaces a vertical panel to provide daylight to the staircase. Alternatively, horizontal wall panels would allow horizontal ribbon windows.

Finishing

The building is intended to be provided as an empty shell that can be finished by the user or by the contractor.

Construction sequence

Figure 31 present a flow diagram of the construction sequence of the main house elements. It does not include design and finishing. The duration of the construction is approximately 26 days or 6 weeks.

1. Foundations - Week 1 -2

Site preparation, digging, and the construction of footing depends on the geotechnical characteristics of the soil and the terrain. In normal conditions, this step would take a week.

Accurate positioning of the column concrete forms and steel anchor bolts is critical and usually requires the use of surveying equipment. The rest of foundation construction is similar to conventional construction with extra care given to reinforcing and tying the columns. The ground floor slab is not installed at this stage.

Because the structure transfers a relatively heavy point load on the foundations, the concrete is let to cure for seven days before the erection of the structure.

2. Structural steel. Week 3

The three steps of the construction of the structural steel are shop drawing (detailing), shop fabrication, and site erection. State-of-the-art CAD programs can produce shop drawings directly from structural concepts. Typically, the shop fabrication can be done in a week, while shipping and site erection by a crew of two with a crane takes another two days. The shop drawing and fabrication phases may start as soon as week 1 and the erection of the structure may take place as soon as the concrete foundation has acquired acceptable strength.

3. Steel deck – Week 4.

The deck sheets are prefabricated, cut to size and shipped to the site. They are installed the day after the steel erection is completed. The installation, which can start just after the completion of steel erection, is a simple operation of hand laying and tack welding of deck sheets on the steel joist. The floor and the roof can be done in one day and by a crew of only two.

4. Roof – Week 4

The roof basis is the steel deck installed during Step 3. The roof finish may vary according to its functions: roof, roof garden, etc. .The steel deck offers an immediate working platform making the roofing work safe and straightforward. The estimated time to complete the roofing is three days.

5. Floors- Week 5

The construction of the floor requires 3 steps: Preparation, installation of services, placement of concrete.

The preparation of the slab on grade with gravel, sand, polyethylene vapor barrier, styrofoam insulation board, and welded wire mesh (see Figure 31) is similar to conventional construction. Plumbing and sewer connections are installed; the floor deck floor receives a wire mesh; hot water radiant heat pipe are then installed and attached to the mesh, as well as, other services, such as electrical conduits and water pipes. 20 MPa concrete grout is then placed and polished in a single day.

6. Walls and windows – Week 6

Assuming the use of light prefabricated foam panel as described above, the construction of the walls has three steps: Design, prefabrication, and installation. The design incorporates the specific building requirements for insulation, windows, services, as well as, inside and outside finish. Prefabrication and shipping usually takes a week to complete. Both design and pre-fabrication may start as soon as Week 1. Panel installation may be done in a single day.

The sequence for the windows is identical and run in parallel to the wall construction: design, prefabrication, installation. The design incorporates the specific building requirements for window orientation, lighting, and energy value. Prefabrication and shipping normally takes a week to complete. Both design and pre-fabrication may start as soon as Week 1. Alternatively, the windows may be pre-installed in the wall panels. Windows installation on site may be done in a single day.

Interior components and services

The steel construction allows for a more logical approach to the design and construction of interior components of a house.

Electrical

Electrical conduits are pre-installed during the main construction phase. Empty channels are included in the prefabricated wall panels. Electrical conduits and connection boxes are attached to the deck prior to placing the concrete. The electrical wires are then chased through this network of conduits during the finishing phase.

Plumbing

A water and sewer connection must be installed in the ground floor slab before placing the concrete. A shaft cut through the steel deck may provide a passage to the first floor. The final installation of plumbing fixtures, sinks, showers, toilets, and tubs can be done in a conventional way. A more efficient method would be to install complete pre-fabricated bathroom units. The 3 m room height allows these units to have an elevated floor containing the plumbing connections.

Heating.

As described in a previous section, the concrete floor may contain a hot water radiant heat system. These systems are usually installed in individually controllable loops to improve comfort and energy efficiency.

Solar energy

Passive solar heating works by capturing the solar energy through a glass panel and accumulating it in a solid mass of preferably dark color. The heated mass radiates part of its energy back into the infrared range, which cannot pass through the glass and is reflected back. The resulting effect is an increase of temperature of the mass that can be used to heat the house through circulation of warm air and convection. A cost-effective way to implement passive solar energy is to install large south-facing windows for capturing solar energy and a concrete floor for accumulating it.

Internal walls

As described previously, the house does not require internal bearing walls. The interior can be left completely open or easily changed according to the needs of the users. Internal walls can be installed in very economical ways using light steel studs and drywall, prefabricated partitions, or prefabricated cabinets. Figure 25 & 26 provide examples of layouts achieved principally by prefabricated cabinets.

Performance

The prototype steel house has equal or superior performances to conventional construction.

Thermal transfer

The foam core panel and roofing system completely enclose the steel frame, eliminating thermal bridges and condensation problems. The house has, therefore, a thermal performance superior to conventional wood construction: Energy leaks through wood studs are eliminated and the envelope itself forms a tighter vapor barrier.

Corrosion performance

As described in the previous section, the steel is completely inside the envelope and therefore, two coats of paint are sufficient enough to provide a long-lasting protection from corrosion.

Fire safety

The building code does not require single-dwelling units to be fire-protected. Gypsum boards can protect the interior and the structure from the foam core wall panels, which are combustible and may emit toxic fumes under heat.

The installation of sprinklers can improve the fire safety. The use of foam concrete or rockwool in the walls can also make the building practically non-combustible.

Acoustic

The mass of concrete floors gives them a better acoustic performance than wood floors. In addition, it eliminates the squeaking floor problem. The foam core panels insulate from the exterior sounds. Foam concrete has a better acoustic performance than plastic foam. However, in both cases, the continuous wall panels spanning many floors may transmit the sound from floor to floor. A research by the SBI shows that this problem can be greatly reduced or eliminated by installing non-continuous gypsum boards that are interrupted at each floor slab.

The presence of the steel structure inside the building has no effect on its acoustic performance.

Cost of structural steel

The cost estimate for the structural steel assumes a conventional, non-integrated construction approach where various, independent contractors fabricate, erect, and finish the building. (See Chapter 7). A design-built approach or pre-engineered building would be more efficient and more economical. Therefore, these estimates form the upper limit.

Table 21: Quotation results

	1 FOB	1 Erected	10 FOB	10 Erected
Min	8,600	12,100	80,000	106,000
Max	15,542	23,933	140,210	224,120
Avg	12,008	17,746	109,314	158,591
Avg Price per unit	**12,008**	**17,746**	**10,931**	**15,859**
Avg Price per ft2	**6.67**	**9.86**	**6.07**	**8.81**
Min Price per ft2	4.78	6.72	4.44	5.89
Max Price per ft2	8.63	13.30	7.79	12.45
Avg price per lb.	**1.19**	**1.76**	**1.09**	**1.58**
Min price per lb.	0.85	1.20	0.80	1.05
Max price per lb.	1.55	2.38	1.39	2.23
Avg Price per m2	**71.81**	**106.12**	**65.37**	**94.84**
Min Price per m2	51.43	72.36	47.84	63.39
Max Price per m2	92.94	143.12	83.84	134.02
Avg price per kg	**2.63**	**3.89**	**2.39**	**3.47**
Min price per kg	1.88	2.65	1.75	2.32
Max price per kg	3.40	5.24	3.07	4.91

76 steel fabricators across Canada received a fax asking if they wanted to quote on a steel structure for a single-family residential construction. The request made clear that the intent of the project was *"to compare the costs of a steel house to conventional wood construction. This house may not be built in a near future, however the design could be used to promote structural steel as an alternative to residential construction."*

19 steel fabricators accepted and subsequently received the drawings and list of materials (see Appendix K) indicating the size, length, and approximate weight of the steel elements excluding the clips, bolts, and other connections. The request for quotation explained that:

"Members of similar or greater structural properties may substitute the elements in the list, if it is required by economical or availability reasons. Canadian steel or steel with high Canadian content

steel should be used as much as possible.
The price should include detailing and the supply of the fabricated steel with one coat of primer, connection bolts and anchor bolts. In addition, the quotation should have the following options:

- *Option 1: Fabricated steel ready to ship and assemble FOB your shop*
- *Option 2: Structure erected in a 100 km radius from your shop.*
- *Option 3: Same as 1 for quantity of 10 (ten) same units*
- *Option 4: Same as 2 for quantity of 10 (ten) same units.*

10 fabricators sent back a quotation, whose results are shown in Table 21

The conclusions that can be drawn from this table are:

- The cost of structural steel is a relatively small portion of the total cost of the house. For ten units, the average price of the structural steel erected is approximately 95 /m2 ($8.82/ft2) or only 14 percent of the completed house.
- The erection adds 50 percent to the cost of fabrication. This cost might be overrated considering that two workers and a crane can assemble the structure in one day.
- The cost for 10 units is only 10 percent lower than the cost for one.
- The price differences are more or less 33 percent from the average. This is an extremely large variation considering that it is for the same product. Table 22 presents the variance from average by province. It indicates that the cost is lower in Ontario than in the other Provinces in Canada.

Table 22: Price variance by province.

Province	10 erected Avg Unit cost	Variance
Ontario	13,491	-15%
Nova Scotia	18,435	16%
Alberta	22,412	41%
New Brunswick	18,830	19%
B.C.	17,970	13%
Average	**15,859**	-

Total cost of the prototype house

Table 23 provides an estimate of the total cost of the prototype house.

A short description of each cost item is given below:

General

Administration

The general administration costs include basic design and engineering, general project management, permits, surveying, and liability insurance

Supervision

The costs of supervision accounts for site supervision and construction quality control; it is estimated to be equivalent to 5 percent of the value of the sub-contracts.

Building base

Site preparation

Site preparation includes the excavation for foundations, slab on grade, sewer and service connections, and back filling after the completion of the foundations works.

Foundations

This item covers concrete form rentals, sonotubes, wire mesh, reinforcing steel bars, drain tiles, concrete installation, damp proofing, and labour for preparing the foundations before pouring the concrete.

Table 23: Cost estimate of the prototype house

General	Cost	%s-t	%tot
Administration	6,800	57%	6%
Supervision base	2,500	21%	2%
Supervision service	1,200	10%	1%
Supervision Finishing	1,500	13%	1%
Sub-Total General	**12,000**		**11%**
Main elements			
Site preparation	1,200	2%	1%
Foundations	3,800	8%	3%
Steel Structure	16,000	32%	14%
Steel Deck	2,600	5%	2%
Floor Concrete	4,300	9%	4%
Steel Stairs	1,100	2%	1%
Roof	3,400	7%	3%
External Walls	7,800	16%	7%
Windows	9,600	19%	8%
Sub-Total Main	**49,800**		**44%**
Cost per ft2	*$31*		
Cost per m2	*$335*		
Services			
Plumbing	5,200	23%	5%
Heating	4,800	21%	4%
Electrical	5,100	22%	5%
Kitchen, Bathrooms	7,900	34%	7%
Sub-Total Services	**23,000**		**20%**
Finish			
Finishing	22,000	77%	19%
Miscellaneous	6,400	23%	6%
Sub-Total Finish	**28,400**	.	**25%**
Grand Total	**113,200**		
Cost per ft2	*$71*		
Cost per m2	*$762*		

Steel Structure

The detailed cost calculation for supplying and installing the steel structure has been provided in a previous section. (See Cost of Structural Steel.)

Steel Deck

It includes the delivery, installation, and tack-welding of the steel deck and the supply and installation of a wire mesh on the deck.

Floor Concrete

The cost includes the insulation of the slab on grade with styrofoam and the placement and finishing of a concrete slab on the main and first floors.

Steel Stairs

The cost includes the labour and the material for installing the stairs made with structural steel support, steel treads, and ramp.

Roof

The cost includes insulation with R-30 isocyanate panels and the delivery and installation of EFDM membrane, and gravel ballast.

External Walls

The cost comprises the delivery and installation of prefabricated foam panels made from steel interior and exterior sheets and urethane foamed-in-place insulation.

Windows

This item includes the delivery and installation of steel mullions, glass panels, and caulking. the glass panels are Low-E, double-pane and argon-filled.

Services

Rough Plumbing

The rough plumbing costs cover the supply and installation of water, sewer, and gas pipes, but not the plumbing fixtures.

Central Heat

The central heat costs include the supply and installation of radiant heat pipes, the boiler, vents, controls, and accessories. The heat pipes are installed on the floors prior to pouring the concrete.

Electrical

The electrical costs include rough wiring and the supply and installation of basic electrical fixtures, service panel, connection boxes, receptacles, lighting fixtures, and phone and TV cables.

Kitchen, Bathrooms

These costs include the delivery and the installation of basic plumbing fixture such as faucets, sinks, showers, and bathtubs, as well as, kitchen and bathrooms cabinets.

Finish

Finishing

Finishing costs encompass doors, drywall, cabinets forming interior walls, painting, and exposed concrete floor sealing. The calculation of these costs is based on the experience from the house in Surrey (see Chapter 4)

Miscellaneous

The miscellaneous costs account for minor corrections and finishing works not defined anywhere else and these are based on the experiences drawn from the house in Surrey.

Final results

The total cost of the finished house is $113,200 or $762 per m2 ($71/ft2). As described above, it includes the design, the general administration, the main building elements, including structural steel, water, electrical, heat services, and the finishing work. The structural steel and main work costs less than $50,000, or on an average, $335 per m2 ($31/ft2), which represents approximately 44 percent of the completed house.

The structural steel is the largest cost item after finishing but represents only 14 percent of the total project.

Conclusion

The construction costs of the prototype steel house are lower than a conventional wood frame house of similar size. The operation and maintenance costs are expected to be lower too because the building is stronger, more flexible, more energy-efficient, and more durable.

The steel structure weights less than 5 tonnes (10,344 lbs.) and costs approximately 14 percent of the total cost of the building.

The installation of floor and roof steel decks is fast and economical, costing less than 2 percent of the total. The concrete floor is a low cost component that combines strength, speed of installation, and increase of thermal mass. The pre-fabricated walls can be installed in a single day. The structure allows the use of large windows. The internal walls can be built very economically and integrated with other functions. Electrical, plumbing, and heating components can be pre-installed or integrated into the concrete slabs, which results in a lower cost of installation.

The site assembly of the main components takes less than 3 weeks. It reduces the cost of labour and allows building in remote sites or difficult climates.

The use of steel is not only an economical solution to single-family residential construction but also a solution toward sustainability as shown in the next chapter.

CHAPTER 9 – STEEL HOUSES & SUSTAINABILITY

What are the performances of a steel house in the context of sustainability? Will steel make a house a "green building"? Or in other words, is red steel green? This chapter will show why *"Nothing can compare with steel in construction as far as sustainability is concerned."*

Sustainability

The human economy is embedded and dependent on the natural ecosystems of our planet. Until this present day, the scale of human economic activity relative to the scale of the ecosystem has been small enough so that this fundamental fact could be largely ignored. Because of the explosive economic expansion of the last half of this century, the ecosystem's ability to support the economy is approaching its limits. Appendix M presents indicators that support this view.

The first environmental limits that the economy is confronting and possibly exceeding are not the limits to nonrenewable resource, as many once anticipated, but rather the limit to renewable resources and to the environment's sink functions- its ability to absorb our wastes. These limits are related to the loss of soils, forest, and water; to the absorption of CO2; and to the destruction of the ozone layer.

The Brundtland commission (1987 UNCED), addressed this issue in the late 1980's and made up the concept of sustainable development, which means " *to meet the needs of the present without compromising the ability of future generations to meet their own needs*". It has since, however, been recognized that sustainability has a broader application than just "development"; hence, the reference to "sustainability". Sustainability can be defined as a process or state that can be indefinitely maintained.

For the Brundtland commission, the four necessary conditions for a sustainable economy are:

1. Produce more with less.
2. Reduce the population explosion.
3. Redistribute the goods and wealth from overconsumers to the poor.
4. Transition from economic growth to qualitative development.

While the second and third conditions are mainly political, the first and latter can be addressed by appropriate application of the technology. Both conditions imply a shift from quantity to quality and an increased efficiency in the use of natural resources. The objective is to stabilize quantitative throughput growth and replace it with qualitative development; and to produce more with less through conservation, energy efficiency, technological improvement and recycling. The goal is the *dematerialization* of the economy, or the absolute or relative reduction in the quantity of material and energy required to serve economic functions.

According to UNCED's estimates, a sustainable economy that would provide for the basic needs of the world population and at the same time keep the ecological balance of the planet, would require a tenfold increase in resource productivity. This means that the amount of wealth extracted from one unit of natural resource should increase by a factor ten. While this goal seems ambitious, a recent report to the Club of Rome identifies more than 50 existing technologies that already use resources four times more efficiently, including 18 that are related to building and housing. (See "Factor Four" in Bibliography)

Triple bottom line

The sustainability concept acknowledges that the world is made up of three closely related systems: nature, economy, and society. Each one has its own imperative or "bottom-line". The ecological bottom-line is to remain within earth's carrying capacity, the economic bottom-line is to ensure adequate material standards, the social bottom-line is to satisfy individual and community needs.

Sustainable buildings need to perform not against a single criterion but against the triple bottom line and produce social and ecological benefits as well as economic wealth. Their design must strive for a win-win-win solution.

Value shift

Obviously, the achievement of a sustainable society requires a "paradigm shift" or a shift in cultural, social, and economic values. A hopeful sign is the fact that, over time, human and social values have changed. Concepts that once seemed extraordinary, such as emancipating slaves, or enfranchising women, are now taken for granted. Sustainability requires new ways of thinking, and new methods for designing, producing, and operating goods and services. It demands a new approach based on the following principles:

- System integration,
- Value optimization,
- Life-cycle planning,
- Impact reduction.

Determining whether the use of steel in residential construction meets these principles will provide an answer to the key question: *Is a steel house a solution toward sustainability?*

System integration

System integration creates a whole from parts that are put to work together, creating a new entity that is more than the sum of its parts. (See Chapter 2.) System integration allows doing more with less by reducing the amount of time, space, energy, and material employed in a building while increasing the number of activities that can take place within it. System integration stimulates dematerialization by increasing efficiency. It means thinking about the design challenge as a whole and not as a superposition of disjointed pieces. It also means promoting teamwork. Integration fights this century's trend towards narrow specialization and disintegration. It demands optimization, not rules of thumb.

Chapter 2 shows that a steel house has a greater level of integration and needs fewer components than a traditional wood framed house. A steel house offers many opportunities of conserving resources at each stage of the life cycle of the building listed in Table 7. A steel house offers the possibility to do more with less.

Value optimization

Optimizing the value means focusing on what services to provide, not just on what products to produce. It means concentrating on real customer needs and putting emphasis on the quality of life in order to deliver less eco-intensive, higher value applications. Value optimization stimulates dematerialization and the transition from economic growth to qualitative development.

Chapter 2 explained that a single-family house has 6 main performance mandates: Spatial, thermal, building integrity, air quality, acoustical and visual. The house must also satisfy basic physiological, psychological and sociological human needs. Table 3 in Chapter 2 shows the performance criteria for meeting human needs and Chapter 3 demonstrates that a steel house meets or exceeds all these criteria.

Physiological

These needs are evidently the most fundamental and they represent the "real customer needs".
A steel house delivers superior performances in every aspect:

- Spatial: by providing functional and flexible space that can be adapted to virtually any usage.
- Thermal: by improving insulation, increasing thermal mass, and allowing the use of solar energy.
- Building: by increasing the structural efficiency and stability, endurance to decay, seismic resistance, durability, and weatherproofing.
- Air Quality: by not using chemically treated material.
- Visual: by allowing the use of large windows for natural lighting.

Psychological / Sociological

Less fundamental, these needs still represent an important factor for the acceptability of steel technology.
Chapter 3 shows that steel houses can be designed to provide psychological comfort and sociological well-being, such as:

- Spatial: by offering habitability, esthetics, views, or spectacular setting.
- Thermal: by contributing to a greater thermal comfort.
- Building integrity: by providing a sense of stability, durability, status, security, appearance, and craftsmanship.
- Air Quality: by allowing to build spacious, airy rooms.

In conclusion, the application of steel is a very efficient way to meet housing criteria. Steel offers the opportunity to increase the value of the building system, to replace quantity by quality, material by information, and therefore is an agent for dematerialization and sustainability.

Life-cycle planning

At the most basic level, sustainability implies that future generations should enjoy continued access to resources. It means taking into account the short and long-term consequences of products and services. It implies not only the state of the planet passed on to future generations, but also the physical capital, such as the infrastructure and the built environment.

The longevity of a building is an important parameter of sustainability because it amortizes the resources over a longer period. A steel house has exceptional durability. Appendix A and Table A-1 present many cases of steel houses that have withstood the test of time and are performing extremely well with minimum maintenance. (See Appendix A 3.1 Stability.) This longevity is due not only to the properties of steel, but also to the stability of the steel structure as a support for the other elements of the house and to the better quality control resulting from pre-fabrication.

Furthermore, the steel in the house is not consumed, only borrowed for the lifetime of the building and, at the end, returned for reusing or recycling.

Impact reduction

The sustainability concept requires also taking into account the individual and cumulative social, environmental and economic implications as well as the direct and indirect consequences of a building at all the stages of its life. Impact minimization requires a complete control of the material chain or closing of material loops. The Life-Cycle Assessment (LCA) is a widely accepted method based on ISO 14000 Standards that allows to evaluate the overall environmental impact of a product. IISI representatives (See Chapter 5) are presently working in ISO 14000 committees to develop a methodology for the LCA of steel.

The LCA is a cradle to grave quantitative accounting tool that comprises four stages: Goal definition and scoping, life-cycle inventory, impact analysis, and improvement analysis.

Goal definition and scoping

The first step of a LCA consists of identifying the assessment purpose, the study deliverable and boundaries and the assumptions based upon the goal definition.

For a steel house, the goal is to determine the environmental impact or benefit of using a building system different from the conventional wood-framed house. The scope is therefore limited to the particularities and main features of a steel house, which are:

1. independent column and beam structures made with steel
2. curtain walls
3. floor and roof steel decks

The main environmental impacts of a building are related to resource consumption, waste production, and land degradation. Therefore, the scope of the environmental assessment may focus on the following aspects:

Input of resources

- Consumption of limited renewable resources such as wood with its effects not only on the decline of limited resource, but also on land degradation, erosion, and habitat destruction.
- Consumption of non-renewable resource such as limestone, iron ore, or coal with its consequences of loss of limited resource, land degradation, and extraction-related environmental impact. This later impact may be significant because on average 14 tonnes of raw material are required to produce one tonne of iron and 10 tonnes of material are required to produce one tonne of cement.
- Consumption of energy with its consequences of loss of limited resources, air pollution, and the increase of green house gas in the atmosphere. This is an important aspect because buildings use 40 percent of the world's energy.

Load and waste to the sink.

- Air emission produced during the manufacture, construction operation and demolition of the building and
    - having a global impact such as green house gases (CO2) or ozone depleting substances (ODS) such as freon
    - a local impact such as particulate matter, nitrogen oxides, heavy metal (lead, zinc, ...), toxic or carcinogen substances (asbestos, PCB, solvent)
    - an indoor impact such as solvent evaporation or radon
- Solid waste from the manufacture of building material, the construction, and the demolition of the building itself.
- Land degradation caused by the setting of the building but also by the services directly and indirectly related to the building industry, and by transportation.

Life-cycle inventory

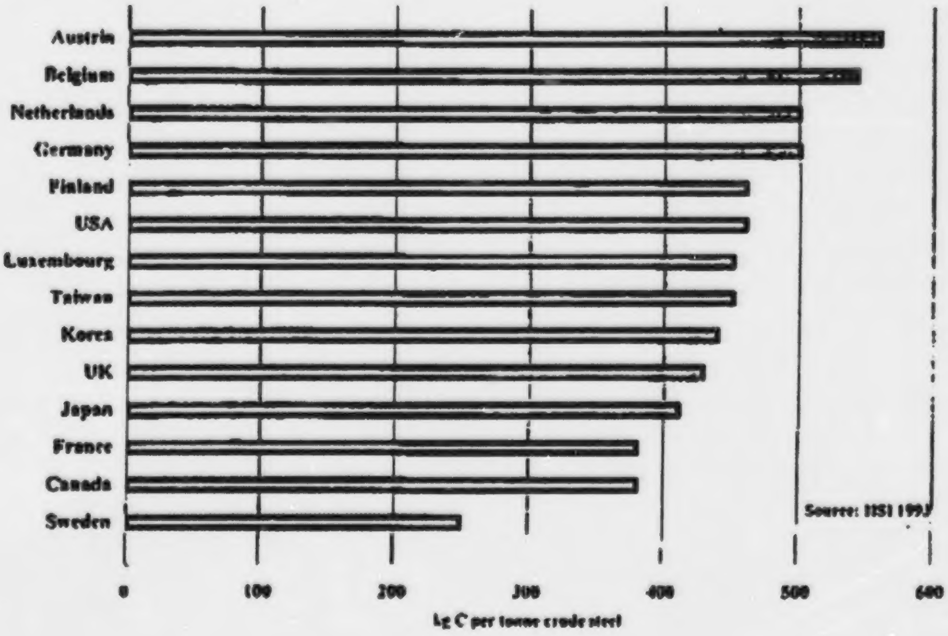
A Life Cycle Inventory (LCI) is an account of the energy and raw material inputs and environmental releases associated with each stage of production.

Chapter 2 explains how steel technology applied to residential construction promotes the conservation of resources and Table 4 and 5 summarize the results. A cradle to grave analysis of a building will typically include all the impacts related to the consumption of resources and waste during its entire lifecycle.

Initial impact

Initial impacts occur during mining, resource extraction, and primary transformation of raw material.

Figure 32: Carbon consumption per tonne of steel



Source: IISI 1993

Energy / CO2

Steelmaking is energy intensive and largely coal-based, either through its direct use as a chemical reactant to convert iron ore to iron or as a fuel for generating the electricity used in steel making and steel processing. Energy purchases represent 15 to 20 percent of steel manufacturing costs. The industry's reliance on coal is important because coal combustion generates more carbon dioxide per unit of energy than other fuels. The Canadian steel industry contributes 2.4 percent of Canada's total green house gas emission. Figure 32 shows the carbon consumption per tonne of crude steel for different countries, assessed by the IISI. With 375 kg Carbon per tonne of steel produced, Canada has one of lowest emission factor in the world. This is due to the extensive use of EAF technology and hydro electricity in this country. The units in the graphic are in kg carbon per tonne steel. The relation between Carbon and CO2 is 44/12 or 3.66. Thus, the typical emission embodied in Canadian steel in 1,375 kg CO2/ tonne steel.

With the widespread application of arc furnaces technology, steel-making is increasingly using recycled steel. In 1997, recycled steel represented almost 50 percent of the 800 million tonnes produced worldwide. Recycled steel accounts for about two-thirds of the steel produced in the U.S., and programs have been implemented to promote even greater recycling of steel materials.

Consequently, the energy consumption and CO2 emission related to the production of one tonne of steel has decreased significantly over the years.

Table 24: Energy in Steel

Embodied energy in steel (GJ/tonne)	
Primary Steel	25.5
Multi-cycle steel	18.9
Recycled steel (from scrap)	17.3

(Source SCI)

According to a study by British Steel, the recycling and reuse yield is a significant factor for assessing the energy and CO2 embodied energy when looking at the many life-cycle stages of a recyclable or reusable material. The study shows that, in fact, a recyclable material with a relatively high-embodied energy, such as steel, has better environmental performance than a non-recyclable material with a lower embodied energy, such as wood.

The steel industry has reduced the energy consumption per tonne of steel and corresponding carbon dioxide emissions by about 45 percent since 1975, largely through investments in new technologies. In the past decade, annual energy consumption was reduced by more than 30 percent.

Air & water pollution

Since the early 1970s, the steel industry's discharge of air and water pollutants has been reduced by well over 90 percent. Today, over 95 percent of the water used for steel processing is recycled. Recycled steel accounts for about two-thirds of the steel produced in the U.S., and programs have been implemented to promote even greater recycling of steel materials.

Land use

Steel has a relatively low land degradation impact. The mining of the iron ore used in the production of 15 millions tonnes of steel in Canada consumes the equivalent of 30 ha of land surface per year. In comparison, 15,000,000 ha of rain forest is cut per year.

Steel in housing replaces the demand for new wood by the use of a recycled and recyclable material. North American wood consumption is higher than anywhere else on Earth. US residents consume 1.83 m3 wood per person per year or about 6 times the world average, which is 0.32 m3. It is estimated that a typical wood-framed house typically consumes from 40 to 50 trees of one-foot diameter. In fact, in North America, the size of houses and the amount of wood per square meter has increased significantly over the last 35 years. According to Ann Edminster, (Green Building Conference, Vancouver):

Table 25: Weight and volume of steel used in the prototype steel house

	m2	kg/m2	kg	
Structural steel			4,686	See Chapter 8 Table 18
Deck	167.23	8.48	1,418	Gauge 22 see Chapter 8 : Floors
Walls. Steel sheets	267.56	4.03	1,079	Gauge 26 Steel sheet both sides
Total steel weight in Kg			7,183	
Total steel volume in m3	0.900			m3 (steel density = 7.9)

- In 1963, the average house was 127 m2 (1,365 ft2.) It housed 3.2 people and used 0.18 m3/m2 of wood (7.38 board foot per ft2) resulting in a wood use per person of 7.14 m3.
- In 1998, the median house is 204 m2 (2,200 ft2), housing 2.6 persons, and using 0.21 m3/m2 (8.1 board foot per ft2.) resulting in a wood use per person of 13.14 m3, which represents an increase of almost 100 percent from the level of 1963.

These numbers are summarized in Table 26, which shows that a steel house uses approximately 38 times less material in volume than a wood house and 2.4 times less material in weight. There is a limit to the rate of regeneration of renewable resources and the renewal of lumber is not keeping up with the pace of logging, causing a significant drop in quality. The use of steel reduces the demand on wood. This reduces the impacts of logging, such as habitat destruction and land degradation.

Table 26: Wood and steel use in residential construction

	Nb	Size	Material use			
	Persons (1)	m2 (2)	m3/m2 (3)	kg/m2 (4)	m3 (5)	m3/p (6)
Wood house 1963	3.2	127	0.19	94	23.77	7.43
Wood house 1998	2.6	204	0.21	103	42.05	16.17
Steel house (7)	*3.5*	*167*	*0.01*	43	*0.90*	*0.26*

(1) Average number of persons per home in North-America
(2) Average size of a north American home
(3) Cubic meter of material per square meter of living area
(4) Density of wood = 500 kg/m3, density of steel: 7,900 kg/m3
(5) Total cubic m3 used in an average size home
(6) Volume of material per person in cubic meter.
(7) Prototype steel house of Chapter 8

Pre-Fabrication impacts

The main environmental impacts related to the fabrication stage include energy, air emission, liquid and solid waste.

Air pollution / Solid Waste

The fabrication of the elements of a steel house can produce toxic discharges and waste, such as:

- Particulate matter and fumes from welding and grinding.
- Zinc vapor from the galvanizing of steel deck elements.
- Emission of ozone-depleting substance (such as Freon) from the manufacturing of rigid insulation.
- Solvent emission from paints.
- Solid waste and fabrication cuts.

Pollution prevention and fabrication planning can reduce these discharges and waste to a minimum. In addition, the use of steel avoids the environmental problems related to wood fabrication such as the use of wood preservers, pesticides, and glue.

Energy

The prototype steel house uses concrete floor instead of wood. The fabrication of cement is energy-intensive and represents 90 percent of the total energy required to produce concrete. The production of one tonne of cement uses 5 GJ of energy, requires 10 tonnes of raw material and emits one tonne of CO2. However, new concrete technology allows replacing up to 60 percent of the Portland cement with fly ash, which is a by-product of coal-fired plant. The prototype steel house uses 14 m3 of concrete. If the 60 percent mix was applied, it will use 2.17 tonnes of Portland cement, resulting in 2.17 t embodied CO2 and 10.85 GJ embodied energy.

Table 27 provides an estimate of the embodied energy and CO2 of the prototype steel house. The table also estimates the embodied energy and CO2 in the main structural components of a conventional wood house of similar size.

The table shows that the main structural components-steel and concrete- of the prototype steel house contains an embodied energy of 165 GJ. The R-2000 energy target for a house of similar size in Vancouver is 50 GJ per year (heating & hot water). Thus, the embodied energy represents only 3 1/3 year of operation energy. The steel house has 23 percent more embodied energy than the wood house but 10 percent less embodied CO2.

Table 27: Embodied energy in the main components of the prototype steel house

Material	**Description**	**Qty (Tonnes)**	**GJ/t**	**Embodied energy GJ**	**CO2/t**	**Embodied CO2 tonnes**
Steel	Canadian Steel (1)	7.18	21.4	153.71	1.375	9.88
Concrete	Flyash 155 kg/m3 Portland cement	2.17	5	10.85	1	2.17
Total				**164.56**		**12.05**
(1) assuming the production is 50% Blast furnace and 50% EAF.						
		m3	GJ/m3 (2)	Embodied Energy GJ	CO2/m3 (2)	Embodied CO2 tonnes
Wood	See Table 26	34.40	3.89	**133.84**	0.39	**13.40**

(2) According to Canadian Wood council.

Construction impacts

The main construction impacts of construction include solid waste, energy, solvent use, and land use.

Solid waste

Construction waste is a major environmental concern. As an example, approximately 47,000 tonnes of construction waste were generated in Greater Vancouver in 1995. Wood is the major constituent of construction waste stream representing 62 percent of the construction waste from single-family residential projects in Vancouver.

Pre-fabrication and the use of steel virtually eliminate the construction waste stream.

Energy / CO2

Energy used during construction is minimal compared to the embodied energy. Pre-fabrication and fast site construction reduces the crew transportation to the site, traffic and air pollution.

Air Pollution

Steel construction and pre-fabrication reduces the use of solvent, glue and other VOC-emitting products.

Land use

As shown in Chapter 3, a post and beam structure can be designed to "*touch the ground lightly*", reduce the impact of the building on the land, or allow to build on difficult sites not suitable for agriculture.

Operation impacts

The main operational impacts of a building are related to energy use during its useful life, such as heating, cooling, lighting, services, and air conditioning.

Energy / CO2

The overall environmental impact is significant because it is estimated that buildings consume 40 percent of worldwide energy. The initial embodied energy is only a small fraction of the total energy consumed during the lifetime of the building. (See Table 27.) In a typical lifetime of 60 years, the operation will consume 80 to 90 percent of the total energy calculated over the entire life-cycle.

According to a study by British steel, the combination of structural steel and thin concrete floor reduces heating and cooling energy requirements because the mass of concrete improves thermal storage capacity and the slenderness increases heat transfer.

South-facing windows and the thermal mass of the concrete floors form a passive solar energy system that reduces energy consumption. Structural steel is complementary to glass walls and concrete floors. Therefore, the use of structural steel in housing promotes alternative energy and the reduction of greenhouse gas emission.

The insulated curtain wall provides exceptional heat and cooling loss protection to a steel house. Additionally, the stability of steel, that is the fact steel doesn't warp, twist, split, rot or settle, results in less air loss around windows and doors as well as foundation and roofing connections.

Air pollution

Steel is a non-toxic material and does not require pesticides or other toxic substances for protection against rot, termites, or vermin. The Healthy House Institute in US recommends steel framing for chemically sensitive and environmentally conscious homeowners who seek good indoor air quality. Galvanized steel exposed to the weather emits zinc, which is considered as a harmful heavy metal. A Dutch study shows that galvanized steel installed outside emits of 33 kg of zinc per year per 1000 m2. This problem does not exist for zinc coated steel used inside the building

Maintenance impacts

Maintenance and replacements occur periodically over the life of the building and some components may be replaced many times over its lifespan. Sometimes, the building is completely renovated and adapted to a new purpose. Maintenance, replacement and renovation create a considerable amount of solid waste. According to Dr. Ray Coles of UBC, the amount of recurring embodied energy added by the successive replacement of material over a period of 50 years is greater than the initial embodied energy.

The use of steel has many positive effects on maintenance. Steel protected from corrosion requires no maintenance. The stability of a steel structure reduces the need for repair of the other elements of the house, such as drywall, floor, doors, or windows. Steel offers a greater resistance to seismic load. Furthermore, the flexibility of a steel structure makes renovation less energy- and waste-intensive. (See Chapter 3)

Demolition

Demolition typically requires intense application of energy and generates waste streams that are disordered, contaminated and physically altered to a point where recycling is difficult.

It is extremely difficult to dismantle and reuse the elements of a traditional wood house. Demolition of a steel building for recycling is fast and relatively independent of the construction details. At the other hand, disassembly of a structural steel frame for reuse can be slow, dangerous, and consequently expensive. However, a steel building can be designed for deconstruction, reusability, and recyclability. That is partially the case of the prototype house of Chapter 8, which can be easily dismantled with the exception of the concrete floors.

Disposal impacts

Disposal impacts are related by the demolition waste stream to landfills.

The magnetic properties and resale value of steel make it both easy and desirable to sort it out from demolition debris. In Greater Vancouver, 60 percent of the construction waste consists of wood debris and less than 1 percent is metal (GVRD statistics.) (See Chapter 5 – SRI.) The other elements of the prototype house can be recycled or reused to a lesser extent. The rigid insulation can be reprocessed and crushed concrete can be used as aggregate.

Recycling impact

Steel is a highly adaptable material and lends itself well to the recycling process. As indicated above, steel is easily separated from the rest of the waste stream. Most scrap steel simply needs cutting to size or compressing before dispatching to a steel plant for remelting.

As shown in Table 27, almost 100 percent of steel waste in Greater Vancouver is recycled.

Recycling programs reduce the solid waste stream. Besides saving landfill space, recycling steel also saves valuable energy and natural resources. Each year, steel recycling saves enough energy to power about one-fifth of U.S. households for one year. Recycling saves other resources because every tonne of steel recycled saves 1.25 tonnes of iron ore, 0.635 tonnes of coal, and 54 kg of limestone. (See Chapter 5 - SRI)

Table 28: Recycling rate of construction materials

Recycling rate in GVRD	
Steel	~100%
Asphalt	85%
Concrete	85%
Drywall	93%
Wood	6%

Impact analysis

The impact analysis consists of assessing the impacts on human health and the environment associated with energy, raw material input, and environmental releases quantified by the inventory.

LCA of a steel house

A complete and quantitative LCA of a steel house is beyond the scope of this report. However, the qualitative analysis in Table 29 shows that the technology has superior environmental performances.

Conclusions

The application of steel to housing is a solution toward sustainability that satisfies many sustainable design criteria. In summary, a structural steel house fosters:

- System integration, using fewer, better integrated components.
- Value optimization, providing effective housing functions
- Life-cycle planning, using durable, reusable, recyclable materials
- Impact minimization, producing lower environmental impact during its entire life cycle.

Consequently, steel allows to do more with less and to reducing the consumption of resources and energy, by providing higher-value, more durable and flexible building system.

The wider application of steel to residential construction will promote dematerialization and the transition from economic growth to qualitative development, which is the main goal of a sustainable economy.

Table 29: Qualitative LCA of a steel house

	A. Structural Steel	B. Curtain wall	C. Decks
1. Initial	**a) Non-renewable:** Steel can be made with 100% recycled steel. **b) Renewable:** Displace the use of wood and replace it by a recycled material **c) Energy:** Embodied energy reduced by newer steel-making technology. **d) Air quality:** CO2 emission reduced if steel made in electric furnace and electricity not produced by fossil fuel (e.g. Hydro) **e) Solid waste:** New steel-making use recycled steel **f) Land:** Use of recycled steel reduces mining operations.	**a) Non-renewable:** A curtain wall is typically made with galvanized steel siding (100% recycled), plastic foam, and glass. Plastic foam uses non-renewable fossil oil, but the total weight is small. Plastic could be replaced by other materials, such as foam-concrete ,cement-straw composite, or rockwool. **b) Renewable:** Displace the use of wood in the envelope. Can use straw. **c) Energy:** Embodied energy is minimal due to the lightweight of the walls. **d) Air quality:** Issue of air emission during the extraction of oil and raw material for glass. **e) Solid waste:** Steel uses recycled steel, glass and foam can be recycled **f) Land:** same as A1f	**a) Non-renewable:** The deck uses galvanized corrugated steel (100% recycled) and concrete. Flyash can replace 60 % of the cement in concrete to reduce embodied energy and CO2. **b) Renewable:** Replace wood joists that often require large pieces (2"x10" x 12') replace it by a recycled material **c) Energy:** Embodied energy in the steel deck is reduced by the newer steel-making technology. The production of cement accounts for 90% of energy used to make concrete Embodied energy in concrete can be significantly reduced by the use of flyash. **d) Air quality:** See A1d for steel. CO2 and other air emission from cement making can be reduced by replacing cement with flyash. **e) Solid waste:** See A1e. Flyash is a recycled solid waste. **f) Land:** See Af1
2. Pre-fabrication	**a) Non-renewable**: Pre-fabrication optimizes the use of material **b) Renewable:** same as A1b **c) Energy:** Energy used during welding, cutting, drilling is minimal. **d) Air quality:** Pollution prevention can reduce toxic emissions from welding, grinding and fabrication. **e) Solid waste:** Fabrication planning and pollution prevention can reduce waste to a minimum. **f) Land:** Factory require industrial land use, source of additional environmental impact.	**a) Non-renewable:** :See A2a **b) Renewable:** See B1b **c) Energy:** Except for windows, the fabrication of curtain walls requires few energy. **d) Air quality:** Issue of ozone-depleting substance used for fabricating the foam, emission during galvanizing process. **e) Solid waste:** same as A2e **f) Land:** See A2f	**a) Non-renewable:** See A2a **b) Renewable:** See C1b **c) Energy:** The fabrication of steel decks requires few energy **d) Air quality:** Pollution prevention can reduce zinc toxic emissions during galvanizing The manufacturing of steel deck by forming steel sheets produces no toxic emission.. **e) Solid waste:** See A2e **f) Land:** See A2f

3. Construction	**a) Non-renewable:** See A2a **b) Renewable:** same as A1b **c) Energy:** Energy used to erect steel is very small. **d) Air quality:** No toxic emission (e.g. solvent) during construction. Some air emission from construction engines and crew transportation to and from the site. **e) Solid waste:** No waste by the use of pre-fabricated elements **f) Land:** Allow to build on difficult sites, with small footprint. Reduce land degradation and competition with agricultural land	**a) Non-renewable:** See A2a **b) Renewable:** See B1b **c) Energy:** Few Energy required to install curtain walls. **d) Air quality:** If no adhesive is used, no toxic emission (e.g. solvent) during construction. **e) Solid waste:** See A3e **f) Land:** See A3f	**a) Non-renewable:** For steel, see A2a. Concrete uses gravel, sand & cement. Flyash can replace cement and recycled crushed concrete the aggregates. **b) Renewable:** The steel deck acting as a form for the concrete, it eliminate the need of wood forms. **c) Energy:** Energy required to erect the steel deck is minimal. Cement in concrete is energy-intensive but can be replaced by fly-ash. **d) Air quality:** No toxic emission (e.g. solvent) during construction **e) Solid waste:** No waste as the deck is pre-fabricated and cut at exact length. Care in ordering and placing concrete reduces concrete waste. **f) Land:** See A3f
4. Operation	**a) Non-renewable:** creates flexible spaces and reduces the need for transformation material **b) Renewable:** See A1b **c) Energy:** Structure inside the envelope reduces the thermal bridges and heat loss. **d) Air quality:** Steel produces no toxic emissions (e.g. formaldehyde or radon) during its lifetime **e) Solid waste:** **f) Land:**	**a) Non-renewable:** Easy to adapt and transform without modifying the structural elements. **b) Renewable:** See A1b **c) Energy:** Better insulation and air tightness reduces heat energy consumption. Feasibility of large window reduces lighting needs. **d) Air quality:** Issue of air emission from the foam during lifetime. Issue of heavy metal toxic emission from galvanized steel siding. **e) Solid waste:** Reusable, recyclable. **f) Land:**	**a) Non-renewable:** Create large plateau easy to modify and renovate. **b) Renewable:** See A1b **c) Energy:** The main advantage of concrete floors: Better heating and cooling system. Passive solar energy **d) Air quality:** use of flyash reduces radon emission. **e) Solid waste:** **f) Land:**
5. Maintenance	**a) Non-renewable:** Protected steel is a very durable material requiring minimum maintenance **b) Renewable:** **c) Energy:** **d) Air quality:** Steel protection and maintenance may use water-based paints **e) Solid waste:** Discarded parts may be recycled. **f) Land:** n/a	**a) Non-renewable:** Stable material that does not warp, and requires fewer repairs. Supports humidity. Issue of steel corrosion and degradation of foam over time. **b) Renewable:** **c) Energy:** **d) Air quality:** **e) Solid waste:** Discarded parts can be recycled. **f) Land:** n/a	**a) Non-renewable:** **b) Renewable:** **c) Energy:** **d) Air quality:** **e) Solid waste:** **f) Land:**

6. Demolition	**a) Non-renewable:** Easy to disassemble, no material input is required **b) Renewable:** No material input is required **c) Energy**: If the structure is designed for deconstruction, the energy required for demolition may be considerably reduced **d) Air quality**: Steel disassembly produces no toxic emissions or dust. **e) Solid waste:** Disassembly does not produce other waste than steel. **f) Land:** Small footprint means easy land reclamation.	**a) Non-renewable:** See A6a **b) Renewable:** See A6a **c) Energy:** Independent from the main structure and easy to disassemble **d) Air quality:** produces no toxic emissions or dust. **e) Solid waste:** Disassembly does not produce waste other than the elements of the curtain wall. **f) Land:** See A6f	**a) Non-renewable:** : No material input required **b) Renewable:** : No material input is required **c) Energy: Some energy required to demolish concrete floor.** **d) Air quality:** Pollution prevention can reduce dust emission. **e) Solid waste**: Produces non re-useable waste **f) Land:**
7. Disposal	**a) Non-renewable:** Steel reused or recycled **b) Renewable:** **c) Energy:** Embodied energy partially reapplied to the next cycle. **d) Air quality:** No emission after disposal, recycled steel considerably reduce CO2 emission during steel-making. (See A1d) **e) Solid waste:** See A1e **f) Land:** See A1f	**a) Non-renewable:** Steel, glass can be reused or recycled. Plastic foam can be recycled. **b) Renewable:** **c) Energy:** Except for steel embodied energy is lost. **d) Air quality:** Plastic foam may release ODS. **e) Solid waste:** Some foam cannot be recycled. **f) Land:**	**a) Non-renewable:** Steel reused or recycled. Crushed concrete may be used as aggregate **b) Renewable:** **c) Energy:** Some energy required to crushed concrete **d) Air quality:** CO2 and dust emission for crushing concrete. **e) Solid waste:** Some concrete may end up in landfill **f) Land:**

CONCLUSIONS & RECOMMENDATIONS

Conclusions

Using structural steel in residential construction is a very efficient and cost-effective method. However, its wider application to the housing market requires a better understanding by the building professionals and the public of the benefits of steel such as higher value, lower cost, greater user satisfaction and above all sustainable technology.

Building with steel requires a new business approach of *Design-Build-Finance* (DBF) where a single company provides all the services from design to after-sale guarantee. This approach is highly compatible with recent trends of the building industry: an explosive growth of the market for metal building system and manufactured homes; an increased number of steel fabricators providing full design-built services; and many consulting engineers and architects offering turn-key services including financing, design, and construction.

The application of steel technology to the Canadian housing market may rely on a well-developed network of steel makers, suppliers and fabricators across Canada as well as on wide availability of local skills, trades and experience.

One disadvantage in relation to traditional wood construction is the requirement of the National Building Code for engineering supervision. An integrated approach such as DBF will however greatly reduce the extra-cost resulting from this requirement.

Finally, *red steel is green*. A steel house is a solution toward sustainability because it offers more value with less material, is more adaptable, uses less energy, lasts longer and is recyclable and reusable.

Recommendations

The next step should be to build a prototype based on the design of Chapter 8.

The structure is low cost and easy to assemble. The other elements can be pre-fabricated and partially installed to show the construction details. This prototype could make an attractive, full-size, 3-dimensional promotional display that could be presented to professionals and the public in trade shows, home shows and fairs.

Interpretative text could explain the rationale of using structural steel in housing and its main advantage. The prototype could be partially equipped with a kitchen, bathroom, or living room and the public should be allowed to visit it and experience themselves how steel can produce pleasant, affordable homes.

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ABBREVIATIONS & ACRONYMS

ACEC	Association of Consulting Engineers of Canada
AISC	American Institute of Steel Construction
AISI	American Iron & Steel Institute
APEGBC	Association of Professional Engineers and Geoscientists
ASD	Allowable Stress Design
BOOT	Built Own Operate Transfer
CAD	Computer-Aided-Design
CCMC	Canadian Construction Materials Center
CCPE	Canadian Council of Professional Engineers
CISC	Canadian Institute of Steel Construction
CO2	Carbon Dioxide
CSA	Canadian Standard Association
CSH	Case Study House
CSIRA	Canadian Steel Industry Research Association
CSPA	Canadian Steel Producers Association
CSSBI	Canadian Sheet Steel Building Institute
CWB	Canadian Welding Bureau
EAF	Electric Arc Furnace
GBTools	Green Building tools:
GHG	Green House Gas
HSS	Hollow Structural Steel
IC	Industrial and Commercial sector
IISI	International Iron and Steel Institute
IRC	Institute of Research in Construction.
ISO	International Organization for Standardization.
LCA	Life-Cycle Assessment.
LSD	Limit State Design
LSF	Light Steel Framing, also called steel studs framing
MBMA	Metal Building Manufacturer Association
MEPC	Management Engineering Procurement Construct
MHI	Manufactured Housing Institute
MTC	Modern Trade Communication
NISD	National Institute of Steel Detailing
NRC	National Research Council of Canada
NRCan	Natural Resources Canada
QC	Quality Control
RAIC	Royal Architectural Institute of Canada
SBI	Swedish Institute of Steel Construction (in Swedish, Stålbyggnadsinstitutet)
SCI	Steel Construction Institute

SDI	Steel Deck Institute
SER	Structural Engineer of Record
SRI	Steel Recycling Institute
SSCI	Steel Service Center Institute
SSE	Specialty Structural Engineer
TCA	Total Cost Assessment.
TCA	Total Cost Accounting
UNCED	United Nation Commission on the Environment and the Development
WWF	Welded Wide Flange

Appendix A - Case Studies

Table A-1 presents an inventory of 158 steel houses built during the 20th century.

The following sections develop in more details the findings presented in Chapter 3 using examples from the steel house inventory to demonstrate how steel houses meet the criteria of feasibility, acceptability and performance described in Chapter 2.

Case Study House Program

The examples often refer to *the case study house program* [CSH], which was an experiment of modern architecture during the 50's and 60's in California, launched by John Entenza, the director of "Arts and Architecture" magazine, in Los Angeles. The objective was to promote the design and construction of affordable single family housing using the concept of modern architecture. The CSH were conceived as low-cost, modular houses, simply made with standards elements and open-plans. From 1945 to 1966, the magazine commissioned 34 projects of which 23 were completed.

After a first period of wood houses, from 1945 to 1949, steel took over the program and all the houses, but one, built in the 50s used structural steel. These steel houses were prototypes of industrialized building as opposed to single performance of modern architecture.

Eight steel CSHs were build: Charles Eames was the first to use steel in his CSH #8 and #9. Soriano builds the "1950's" CSH in steel, followed by three houses by Craig Ellwood, CSH #16, #17, #18, and two houses by Pierre Koenig CSH #21 and #22.

These steel CSHs were successful and economical despite the prototype approach and the difficulty of dealing with the relatively new technology of steel. The CSH program

Figure A-1:
Case Study House #21, by Pierre Koenig

brought a valuable experience on the potential of structural steel in residential construction.

Further details on the CSH can be found in the reference on architecture in the bibliography and particularly, in the book of Esther Mc Coy " Case Study Houses Program".

1. Feasibility.

They are many examples in the past demonstrating the feasibility of steel houses and the fact that they can be built at low cost or at cost comparable to traditional construction.

1.1. Extremely Low Cost

Examples of steel houses that were built at extremely low-cost are:

(67)	Spender house by Richard and Sue Rogers, a free standing house, separate studio, courtyard for £12,500 (or CAD$ 25,000 in 1968.)
(70)	Roger house, made with portal frame and industrial refrigerator panels.
(86)	Maison Van Den Bosshe by Ian Ritchie, built for £15,500 (or $30,000 in 1976.)
(139)	Home in Belair by Rick Bzowy, costing A$ 135,000 (or CAD$ 125,000 in 1994.)

1.2. Cost Comparable to wood.

Examples of steel houses that were built at comparable cost to traditional wood construction are two architects' houses:

(29)	Quincy Jones house.
(62)	Duncan Richards house.

1.3. Low Cost house.

Other examples of low-cost steel houses:

(13)	Katz house, designed by Raphael Soriano with standard elements.
(23)	Tropical house by Jean Prouvé (1951), a prototype of low-cost manufactured building for tropical dwelling.
(27)	Maison Prouvé by Jean Prouvé, in France (1953). Use of prefabricated steel elements and recycled elements.
(44)	Saharan Habitat by Jean Prouvé.
(46)	CSH #22. Stahl house built by Pierre Koenig with standard profiles.
(64)	Buckland Cop by Michael Manser. The houses designed by Michael Manser are low-cost, made with prefabricated building elements and assembled like a meccano.
(65)	Forest Lodge by Michael Manser. - See comments on (64)
(70)	Roger house, a light and economical building.
(73)	Capel Manor by Michael Manser - See comments on (64)
(82)	Mancett house by Michael Manser - See comments on (64)
(102)	Gloster house by Gabriel Poole and using the quadro-pod system easy to install by hand and economical.
(111)	David and Pam Noble house by Gabriel Poole. - See comments on (102).
(106)	Hoffman house by Ed Duc made with a "Kit of parts" assembled in 4 days and finished by the owner.
(113)	McCorkell farmhouse by Peter Elliott, built with metal shed technology.
(118)	House by Brian McKay-Lyons built in Halifax for CAD$ 580 per m^2 (CAD$54 per square foot in 1990).
(144)	La Viulca housing system by Jose Ora in Venezuela.

(152)	Jungerhalde house by Martin Cleffmann, made with lightweight building components.

2. Conservation of Space

Structural steel promotes the conservation of space in many different ways:

2.1. Construction in difficult sites

Building on steep hillside and sloped sites is one of the most obvious and often spectacular applications of structural steel. Steel is light and needs few supporting points, (pier or pile foundations) reducing cost for civil works and leaving the site relatively undisturbed.

Famous examples of hillside steel houses include:

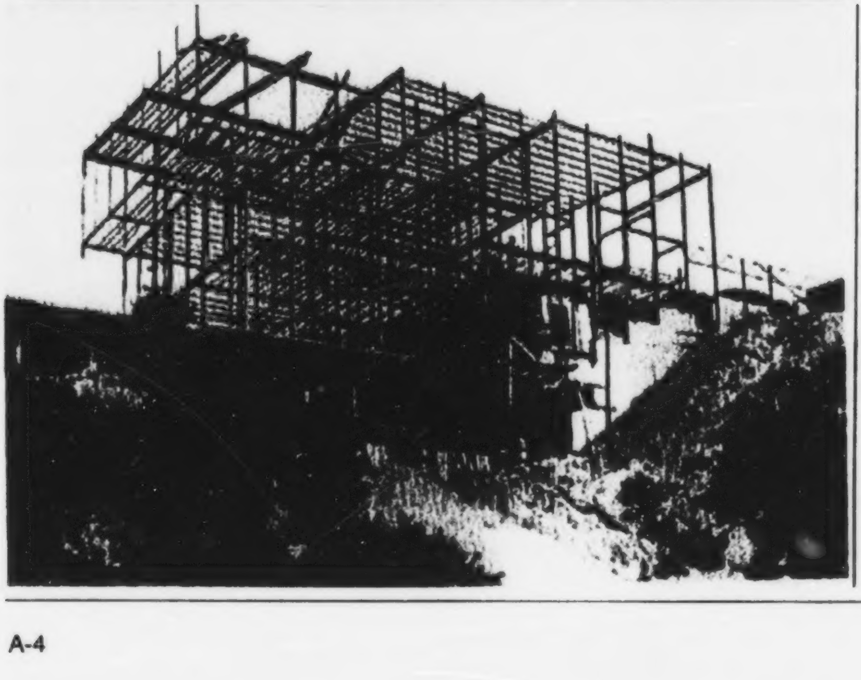
(5)	Lovell health house built on a steep hill over Los Angeles.
(46)	CSH #22 or Stahl house built on an eagle nest above Los Angeles.
(107)	Frishknecht house, a four-story steel frame built in 3 days.

The above examples use steel in a traditional post and beam arrangement. Others use bridge-like trusses to support the house.

House-bridges or *house-trusses* may take many different forms:

(28)	Turramura house, a spectacular house built in a double cantilever steel bridge.
(30)	Richardson house, a house built with a lattice truss.
(33)	McIntyre house, suspended to a "A" frame structure.
(80)	McIntyre house, a daring Rock-anchored cantilever truss.
(105)	Clarke house, built on a double cantilever steel bridge.
(153)	Pritchard's house, built on a double cantilever structure with only 4 piers. The main structure has a central span of 15 m (50 ft.)

Figure A1-2:
Lovell House by R. Neutra, during construction.



Other outstanding examples of houses taking advantage of structural steel to occupy difficult and steep hillsides are:

(32)	Smith house.
(48)	Branch Lane house.
(53)	Bernard Levy house.
(57)	Kenneth Klaxton's parent house.
(58)	House on a cliff by Masahiro Chatani.
(60)	Alsmonbury house.
(75)	Mozin house in Belgium.
(61)	Brumwell house.
(132)	McKenzie house.
(133)	Clarke house #2.
(135)	O'Connor house in Ireland.
(138)	Schwartz house.

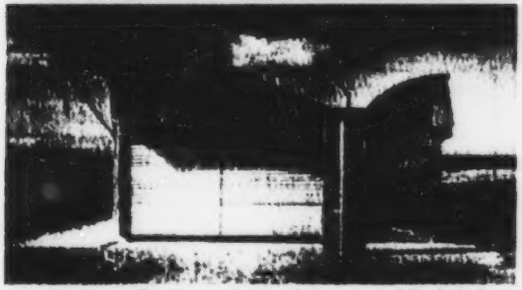
Sometimes the challenging site is a marsh where foundations are difficult and expensive to build:

(155)	The house in Rekem, Belgium by Swinkels Passchier solved a marsh site by driving pile and using a steel frame.

2.2. Small & light footprint

Economic, climatic and environmental priorities may require minimizing the impact on the land and reducing civil works and excavation. By *"touching the ground lightly"*, pier or pile foundations cause less interference with the site than wall or slab foundations.

Figure A1-3:
Bingie farm, by Glenn Murcutt, Autralia



Many recent houses in Australia are using this technique:

(34)	Hunter / McKim house, an experimental steel frame house.
(37)	Russel William house, same as 34.
(40)	Sands house, same as 34.
(43)	Bingie farm, a beach house integrated into the Australian landscape.
(84)	House at Bayview, a house designed to fit in the Australian bush landscape.
(100)	Ball-Eastway house, a house resting on steel columns and raised above ground.
(102)	Gloster house, an experimental building system using the "Quadro-Pod system" that can be assembled by hand.
(111)	David and Pam Noble house, same light and open system as in (102.)

An example in South-America is:

(144)	La Viulca housing system built with steel to minimize excavation and foundation costs.

2.3. Addition to existing building

A steel frame is a perfect solution to the complex technical problems posed by the addition of a new building to an old structure.

Two outstanding examples in residential construction are both in France:

(9)	The Maison de verre by Pierre Chareau, in Paris, is an infill of two lower stories in a four-story building, a tenant of the upper story refusing to move. Eleven W-flange columns support the upper floor, and glass blocks replace the outside walls that are free of bearing loads.
(122)	Maurios house by Georges Maurios in Paris. The challenge was to add a new studio to the rooftop of an old villa. Steel allowed the addition to be as light as possible, so the old walls of the villa below could support it.

2.4. Flexibility

A steel structure offers the possibility of long span and an internal space free of bearing walls. As a result, the layout is completely free and flexible, and may be easily finished or modified to accommodate new needs. The interior may keep a completely *open plan or* be organized with *light partitions*.

Open plans

Open plans are the most striking characteristics of the possibilities offered by steel structures.

Famous examples of open-plan houses include:

(17)	Glass house by Philip Johnson. A steel and glass box, totally free of interior walls.
(24)	Farnsworth house by Mies van der Rohe. One of the landmark of modern architecture.

Other well-known examples are:

(64)	Buckland Cop, designed by Michael Manser with the objective of an open, quick, precise and relatively economical house.
(65)	Forest Lodge, same as (64.)
(73)	Capel Manor, same as (64.)
(78)	Laurie Short house, of Glenn Murcutt, influenced by the "glass house" of Philip Johnson.
(82)	Mancett house, same as (64.)
(86)	Van Den Bosshe house, designed to be simple and economical.
(139)	Home in Belair by Rick Bzowy. A functional and minimalist house with an open plan.
(152)	Jungerhalde house, a townhouse designed to be modifiable by the users.

Internal partitions.

When internal walls are required, they can be installed in very economical ways using light prefabricated partitions, prefabricated cabinets or moveable partitions.

Light pre-manufactured partitions are shipped to the site for easy and fast installation. This was the norm in most projects of the CSH program:

(15)	CSH # 8, which uses industrial panels, by Charles & Ray Eames,
(18)	CSH # 9 a more sophisticated application than in #8, also by Charles Eames
(26)	CSH #16 or Salesman house, by Ellwood.
(31)	CSH #17 or Hoffman house, also by Ellwood,
(42)	CSH #18 or Fields house, by Ellwood.
(45)	CSH #21 or Bailey house, by Koenig.
(46)	CSH #22 or Stahl house, by Koenig.

Pre-manufactured cabinets forming walls are an innovative and effective method to conserve space while providing storing and partition. This technique was extensively used in the houses built in the 50's in California.

(20)	Olds house, by Soriano
(21)	Shulman house, by Soriano
(22)	Curtis house, by Soriano
(36)	Eichler house, an experimental house designed by Quincy Jones.

Moveable partitions allow future changes in the plan or new use of the building as in

(97)	Spence-Webster house which was designed "for all eventualities"
(88)	Architect Bill house by Remo Bill, which was originally an exhibition pavilion, then became a showroom with an office, and finally a house

2.5. Do-it-yourself

Steel structures can provide in a very short notice a protected space for low-cost, do-it-yourself finishing. Two examples of this technique are:

(106)	Hoffman house, which was designed as a kit of parts to be assembled by the owner.
(112)	Jourda-Perraudin house, which is a wooden box protected by a steel canopy

2.6. Expandability

The modularity of steel structure allows an easy expansion of the building by installing additional portals and "pushing the walls."

An example of the application of this technique is:

(74)	House of Ronnie Talon in Dublin

3. Conservation of Material

3.1. Structural efficiency

Steel is the construction material with the highest strength to weight ratio. (See Table 1-Chap.2) Although wood is lighter than steel, a steel structure will be 2.23 times lighter than a wood structure of same strength. In addition, steel elements have structurally efficient profiles such as wide flange beams, channel and tubes.

Pre-engineering

An accurate structural analysis and adequate sizing and detailing of the steel elements are essential to the design of a safe and cost-efficient building. In most cases, a structural engineer calculates the steel after the completion of the architectural plans. However, in some of the steel houses analyzed, the engineer was invited earlier to be part of the design team and was able to give input during the conceptual stage. This resulted in greater cost saving because of a more articulate design and better integration between the structure and other elements of the building.

Here follows some outstanding examples resulting from a close collaboration between architects and engineers.

Together, the architect Michael Manser and the engineer Jack Dawson designed outstanding steel houses such as:

(59)	Cliffhanger.
(64)	Buckland Cop.
(65)	Forest Lodge.
(73)	Capel Manor.
(82)	Mancett house.

The engineer Mark Whitby demonstrated that structural steel can be used very effectively and economically in three low cost houses built by architects for themselves.

(105)	Clarke house designed with Chris Clarke.
(128)	Winter house designed with John Winter.
(129)	McClymont house designed with McClymont.

Tony Hunt, a British engineer, also proved that steel and precision yield lightness and economy in projects such as:

(67)	Spender house designed with Richard and Sue Rogers.
(70)	Roger house designed with Richard and Sue Rogers.
(72)	Hopkins house designed with Michael & Patti Hopkins.
(86)	Van Den Bosshe house designed with Ian Ritchie.
(97)	Spence/Webster house designed with Robin Spence and Robin Webster.

Increasingly more sophisticated computer programs ease the task of optimizing the material.

For Mark Whitby *"The welcome forecast that building codes will be adjusted to the increasing ability to make accurate complex calculations implies the lightest possible structure in the future."*

Seismic resistance

In seismic zone, steel is used for its strength and ductility.

This is the case for:

(5)	Lovell health house, built on an hillside, successfully resisting since 1931 to various Los Angeles earthquakes.
(150)	House in Minamisuna by Kazuhito Namba in Minamisuna.

Stability

Steel does not twist, warp or split. It does not shrink or swell with time or humidity changes, so steel contributes to better drywall and exterior appearance, as well as the fit of doors and windows. Steel is a noncombustible material and has a great stability over time.

Many steel buildings have successfully withstood the test of time for more than a century and are performing extremely well with minimum maintenance as shown in:

1	Coventry Street Cottage in Australia made and shipped by British Iron Foundry. This house built in 1853 is an example of the longevity of steel.
5	Lovell health house in Los Angeles has extremely well withstood earthquakes and the damage of time with minimum maintenance.
9	Maison de verre by Pierre Chareau. This house built in 1932 surprises by the crisp and timeless appearance of its steel elements.

3.2. Efficient profiles and sub-assembly

Steel elements can be optimized to provide optimum and predictable structural properties. The designer has the choice between many types of profiles, trusses, semi-manufactured elements, pre-engineered sub-assemblies, portal systems or more complex forms.

Standard profiles

Steel factories produce standard profiles W, I, C, tubes, and so on, with optimized and predictable structural properties that can be cut at the desired length. The exact sizing of elements both in section and length eliminates the waste of material on site as well as the oversizing often seen in traditional construction. Many architects used this functional and minimalist approach and built economical steel houses by optimizing the use of material. The CSH made an extensive use of standard profiles and industrial elements. (See CSH)

Many steel houses followed the example and used standard profiles:

(119)	The Pesman house by CePeZed in Holland.
(120)	3, Schuterstraat by CePeZed in Holland.
(124)	The Newman house by James Grose in Australia.
(126)	The Ellis-Miller's own house in UK.
(152)	The Jungerhalde house by Martin Cleffmann in Germany.
(156)	The house in Shimogamo by Waro Kishi in Japan.

Semi-manufactured elements

Open-web joists, castellated beams, lattice beams, space frames are more costly that standard profiles but offer greater structural properties, thus weighting less at equal strength. In some projects, the elements can be assembled by hand. The openings in the web may act as chases for pipes, ducts, and services. Examples of house design using these techniques are:

Open-web and lattice beam:

(5)	Lovell health house.
(13)	Katz house by Raphael Soriano with "Lattis" trusses a proprietary truss system developed after WWII.
(15)	CSH # 8 by Charles & Ray Eames
(35)	US Gypsum Research house by Quincy Jones.
(72)	Hopkins house
(85)	Schulitz house by Helmut Schulitz
(113)	McCorkell farmhouse in Australia

Castellated beam:

(88)	Architect's Bill house by Remo Bill in Switzerland
(106)	Hoffman house by Ed Duc in Australia

Space frame:

(99)	Patera System by Richard Hopkins with Mark Whitby, engineer.

Fabricated portals

Stamping and welding steel plates is a technique for low cost mass-production, commonly used in the manufacture of complex steel objects, such as automobile body parts.

The French engineer, Jean Prouvé, successfully applied this technique to his housing projects:

(16)	Metropole house.
(23)	Tropical house for Niger.
(44)	Saharan Habitat.

Complex forms

Steel is easy to form, to bend and to weld and can provide any desired effect, complex form and result with a minimal and economical use of material.

Examples are the houses of Edward Niles in California that combine efficient solar technology with futuristic spacecraft look and complex and beautiful steel structures:

(117)	Sidley house.
(136)	Wilen house

Other outstanding examples of sculptural steel houses are:

(157)	Eppich House by Arthur Erickson, which represents the esthetic vision of flowing cast steel and makes extensive use of chrome and stainless steel.
(142)	House Psyche made with Y-shaped steel beams by René van Zuuk in Holland.

3.3. Simplicity

The steel may be hidden or covered. Steel covered in the walls offers better fire protection than if it was left exposed. Hidden steel gives to the house a more traditional aspect.

Some examples of steel houses with hidden steel are:

(18)	CSH # 9 or Entenza house.
(48)	Branch Lane house by Peter Stead in U.K.
(60)	Alsmonbury house by Peter Stead in U.K.
(154)	Sekishui house, prefabricated housing program in Japan.

Many designers, however, have taken the opposite approach and left the steel structure partially or totally exposed. This method brings substantial saving in labour and material and corresponds to the ideal of industrialization and honesty of modernism. The trade-off is a reduction of fire-protection and the need for greater care in manufacturing and assembling the steel elements - There is no second chance, no gradual stiffening and no possibility of covering-up. *"Steel is as good as its detailing."* said Pierre Koenig. The danger is, however, that complex refinements increase the total cost of the project. Mies van der Rohe went over budget in the Farnsworth house, which has an external frame welded on site with all bolts and connectors ground to give the appearance of absolute simplicity and continuity.

Nevertheless, exposed steel is the norm rather than the exception. It is usually a desired effect well accepted by the owners rather than a trade-off for cost saving. Over the years, exposed steel has become a symbol of modern steel house and as such, has become an acceptable, marketable image.

3.4. Recycling

Recycling is one of the most effective methods for conserving material resources. Modern mills can produce structural profiles from 100 percent recycled steel (see Chapter 1, *sustainable steel*) and at the end of the building lifecycle, the steel can be recycled and sent back to the mill. An even more effective solution is to reuse the elements in another application or to disassemble the whole building and put it to use in a new location.

Examples of steel houses that found a new vocation:

(7)	Aluminaire by Albert Frey started as an experimental prefabricated housing demonstration project for the exhibition of New York, in 1931. After the exhibition, the house was disassembled and re-erected as country house.
(8)	"A-Serien" house built by Erik Friberger was an experiment similar to (7) made during the Swedish exhibition of 1932. Later on, it became a beach house on the South-West coast of Sweden.
(88)	Remo Bill house is at its third life.
(69)	Field house by Georgie Wolton now dismantled and in storage, has completed its first life and awaits another.

The structural components of a steel house generate very little waste. The steel is completely recyclable and has a resale value. Builders reduce their disposal costs, and divert material from local landfills.

3.5. Concrete floors.

Structural steel and concrete floors are complementary. The most common method is to lay a steel deck on the steel beams and joists. The deck acts as a form for the concrete floor eliminating the need for temporary support, forms and shoring. The result is a composite structural system, which puts in compression the top concrete slab and in tension the steel deck and structure. Because concrete works best in compression and steel in tension, the net effect of this arrangement is an efficient and rigid floor system. Beside its structural properties, concrete in floor construction offers many other advantages:

- low cost and ease of installation,
- superior sound-proofing, as a result of mass increase,
- fire resistance,
- large thermal mass, resulting in a more constant temperature and less variation in relation to outside temperature,
- possibility to implement passive solar energy for reducing heating requirements (see 4.3.),
- possibility to embed water pipes in the concrete and install a radiant heat system,
- possibility to lay electrical conduits and plumbing pipes in the concrete,

3.6. Conservation of other building materials.

A steel structure promotes the conservation of other materials in the buildings. In particular, the external walls are relieved from bearing loads and can be made with lighter material or entirely with glass. The foundations are smaller because the building is lighter and a steel structure can stand on piers and does not require perimeter foundation walls.

Many steel houses benefited from using light and low-cost material in their external walls:

(5)	Lovell health house by Richard Neutra used prefabricated panels.

Jean Prouvé developed different modular and easy to install wall panel systems for low cost portable housing:

(6)	BLPS -by Jean Prouvé in 1930 used interlocking, double skinned pressed steel panels,
(16)	Metropole house by Jean Prouvé responded to the post-war housing crisis in France with fast construction and prefabrication technology and light weight panels.
(23)	Tropical house for Niger-1951 by Jean Prouvé was a prototype for manufactured building for tropical dwelling designed for air transportation.
(44)	Saharan Habitat - by Jean Prouvé - 1958, was a prototype of manufactured house for desert dwelling with curved roof panels and wall panels.

The CSH used different system of prefabricated panels

(15)	CSH # 8 or Eames house by Charles & Ray Eames.
(18)	CSH # 9 or Entenza house by Eero Saarinen, Charles Eames.
(26)	CSH #16 or Salzman house by Craig Ellwood.
(31)	CSH #17 or Hoffman house by Craig Ellwood.
(42)	CSH #18 or Fields house by Craig Ellwood.
(45)	CSH #21 or Bailey house by Pierre Koenig.
(46)	CSH #22 or Stahl house by Pierre Koenig.

Other examples are:

(70)	Roger house uses refrigerated trucks insulated panels around a steel structure.
(52)	DEW Line project designed by Pierre Koenig for the Canadian North in 1960, using sheet-steel thermal panels.
(81)	Brumwell house by Alan Colquhoun & John Miller, in UK using GRP insulated panels.
(99)	Patera System by Richard Hopkins, with a proprietary panel system.
(106)	Hoffman house in Australia, designed by Ed Duc as a system building with light steel and panel to be assembled by the owner.
(119)	Pesman house by CEPEZED in Holland, which uses stainless steel panels

Since the structural steel takes all the loads, the external walls can be fully glazed. Well-known examples of glass houses are:

(9)	Maison de verre of Pierre Chareau, which makes extensive use of glass blocks
(10)	House of Tomorrow, a glass box for the exhibition of Chicago.
(11)	Crystal house, a glass house by Fred Keck.
(17)	Glass house of Philip Johnson, a fully glazed box free of internal partitions.
(24)	Farnsworth house, the most famous landmark of steel and glass house
(38)	Eichler Home X-100, a prototype for mass production of low-cost steel and glass houses.
(45)	CSH #21, an experimental and low cost steel and glass house.
(46)	CSH #22, an experimental and low cost steel and glass house for John Entenza.
(57)	Kenneth Klaxton's parents house, a steep hillside glass box.
(72)	Hopkins house, a glass box with open plan.
(78)	Laurie Short house, a steel and glass pavilion strongly influenced by Philip Johnson.
(97)	Spence / Webster house, a steel and glass box with movable internal partitions.
(109)	Schmidt house, a steel & glass house, originally designed by Maynard Lyndon
(121)	House in Portland, by David Rockwood, a fully glazed steel and glass box.
(157)	The Eppich house designed by Arthur Erickson is totally enclosed by glass blocks and glass walls.

A structure transfers the building loads to the ground via the foundations. Since the walls are not load bearing and are attached to the steel, they do not transfer any force to the ground. The traditional perimeter wall foundations can be replaced by a simple and economical pier foundation system below each column. Since a steel house is light and needs only pier foundations, the total amount of concrete and the cost of civil works can be greatly reduced.

The simplification of the foundations allows building on difficult sites with a light footprint (see 2.2.)

4. Conservation of Energy

4.1. Embedded energy

Conservation of energy "fossilized" in the construction material is becoming an increasingly important design issue. In this context, steel has made enormous progress over the years:

Energy consumption of modern steelmaking arc furnaces has decreased by a factor two over the last 30 years.

The newest arc furnaces are now able to process 100 percent scrap metal into new structural members, reducing the amount of energy consumed in the extraction of raw materials and the primary production of iron.

Progress in computer technology has permitted the optimization of the steel structure and the reduction of the amount of material and energy used in a building.
For Mark Whitby "*The continuing development of computer applications for the design of structure will make for significant savings, particularly where modes of failure are analyzed or energy consumption modelled.*"

North American mills are now producing a new standard grade for structural steel with an increase of strength by 17 percent at no cost increase.

4.2. Thermal conductivity

The design and location of the steel elements in relation to the envelope are a determining factor to the thermal performance of the whole building system.

Envelope penetration

A steel element passing through the envelope will have an effect on energy performance, condensation and corrosion.

Many steel houses, however, are built in warm climate, such as Australia and Southern California, and use exposed steel beams penetrating through the walls. Thermal bridges do not seem to be an important issue in these regions, although recent studies in California (*Factor Four*, by Amory Lovins, p.15) show that improvements in the design envelope can create opportunities to cut by half energy required for cooling.

Many steel houses have an exposed steel structure in the plan of the external wall and infill panels and glass inserted in the steel frame. Most CSH and houses designed in California at the same period used this technique:

(15)	CSH # 8
(26)	CSH #16.
(29)	Jones house
(31)	CSH #17.
(36)	Eichler house
(38)	X-100
(42)	CSH #18.
(45)	CSH #21.
(46)	CSH #22

Similar techniques applied in colder climate seem to ignore the issue of energy conservation. This is the case for:

(156)	the house in Shimogamo, Japan, which reproduces a traditional tatami house in steel.
(157)	the Eppich house in West Vancouver, Canada, by Arthur Erickson which has walls made with heavy steel framing glass blocks and infill glass panels

An interesting solution to the problem of thermal bridging was found in:

(155)	House in Rekem, Belgium which has in the plan of the wall a steel structure composed of two C channel with intermediate insulation.

External Frame

Depending on connection details, houses with an external steel frame can be less energy efficient.

According to Glenn Murcutt, the Australian architect:

(78)	Laurie Short house, a Australian glass box with external frame, was a big energy consumer

The same was true for its precursor

(24)	the Farnsworth house, which has to endure the much colder climate of Illinois.

The architects Jourda-Perraudin applied an innovative solution to their own house:

(112)	Jourda-Perraudin house, which has a steel and fabric canopy completely independent of the wood house that it protects from elements.

Totally enclosed Steel frame.

When the steel frame is completely contained in the envelope, a steel house can have a high thermal efficiency. The envelope insulates the skeleton from the outside temperature, eliminates thermal bridges and condensation and protects the steel from corrosion.

The combination of an internal steel frame and external insulated panels can bring significant saving in energy, time (see "time" below) and costs.

Examples of houses with internal frame are:

(2)	Dymaxion or 4-D house by Buckminster Fuller, an energy efficient and economical circular house around a central mast.
(52)	DEW Line project of a prefabricated house for the Canadian north, built with sheet-steel thermal insulating panels
(70)	Roger house, using a steel portal frame totally enclosed in refrigerated truck panels
(81)	Brumwell house with light "GRP insulated panels" supported by circular steel column with branching supports.
(119)	Pesman house made with pipe columns, I beams and insulated stainless steel panels

4.3. Solar energy.

A passive solar heating system captures the energy from the sun through a glass panel and accumulates it in a solid mass of preferably dark color. The heated mass radiates back part of its energy in the infrared range that cannot pass through the glass and is reflected back. The net resulting effect is an increase of temperature of the mass that can be used to heat the house by circulation of warm air (convection.). A cost-effective way to implement passive solar energy is to install large south-facing windows and concrete floors that suit well to structural steel (see 3.5. and 3.6.) Therefore, a steel house is a step towards the use of alternative energy and therefore the reduction of green house gas emission.

Examples of houses using passive solar energy are:

(117)	Sidley house by Ed Niles
(130)	Iron One, an experimental house with large windows, and passive solar system.

5. Conservation of Time

Building a house is time-consuming. Most technologies have made enormous progress during the last century, but building houses still represent "*a medieval process of a traveling factory*", as described by Jan Pesman of CePeZed. In contrast, steel is fast and "*a very rational way of building*" (Pesman). For Michael Manser, steel is "*Easy to construct, quick, precise and relatively cheap*." A steel structure offers many opportunities for conserving time at different periods of the life cycle of the building: fast and easy assembly, prefabrication, do-it yourself, low maintenance, and ability to be disassembled.

5.1. Prefabrication of steel elements

The construction of a steel house starts in a factory. The elements of the structural system are designed, prefabricated and prepared for site assembly. This industrial process in controlled environment gives a better control on time, material, quality, precision and cost.

- *Post and beam.*

The most economical structure is a simple post and beam system made with standard profiles (H, W, I, C, tubes). The simplicity and low-cost of this system made it the most widely used. (see 3.2.)

- *Trusses*
  Open-web trusses and castellated beams offer greater structural properties with less material. They are manufactured by automated and computerized process and mass-produced at low cost. (See 3.2)
- *Complex shapes*

More complex structures are also produced in factory at reasonable cost, provided that the design and assembly are systematic. Regardless of its complexity, a structural steel building can be made simple and economic by the repeated series of the same structure. (See 3.2)

Examples of the "extrusion" of portal frames are

(92)	Wave house by Morrice Shaw, made with a series of pre-welded tubular frame in barrel vault.
(117)	Sidley house by Ed Niles
(136)	Wilen house by Ed Niles.
(151)	River View house in Seoul.

The assembly and pre-welding in a factory of large subsets of the structure can increase the quality and reduce site works and costs.

Examples of pre-assembled subsets:

42)	CSH #18. Fields house by Craig Ellwood, prewelded and transported to the site.
(92)	Wave house (see previous table).
(94)	Andrews Farm house, made with welded frames, prefabricated and transported to the site.
(99)	Patera System, a building system developed for light industrial building and housing.
(142)	House Psyche by René van Zuuk, with sculptural Y shaped cantilever columns.

The increased weight of large pre-assembled sub-systems adds to the complexity of transportation and erection. Most homebuilders and do-it-yourself owners lack the knowledge and the equipment required for assembling large and heavy elements of steel. Therefore, a radically different approach is to design prefabricated steel elements light enough to be manhandled. Cost-efficient structural systems are modular and made with standards elements and simple connections. Steel houses using such "human-scale" system are amongst the most commercially successful to date. The Quadro-pod system developed by Gabriel Poole, uses square tube columns and bolted branches of round tube to obtain a modular 3m x3m structural entity.

This system was originally developed for export of low cost housing to South East Asia and later was applied to:

(102)	Gloster house
(111)	David and Pam Noble house.

5.2. Fast assembly

The site assembly of a prefabricated steel structure can be very fast. The frame of a steel house can be erected in less than a day. Examples of remarkably fast assembly of structures are:

(5)	Lovell health house, erected in 40 hours, (in 1929.)
(10)	House of Tomorrow, erected in 48 hours, (in 1933.)

(22)	Curtis house, erected in 1 day.
(36)	Eichler house, erected in 2.5 hours.
(103)	Yacht house, erected in 5 hours.
(105)	Clarke house, erected in 8 hours.
(106)	Hoffman house, erected in 4 days.
(107)	Frishknecht house, erected in 3 days.
(119)	Pesman house, erected in 1 day.
(120)	3, Schuterstraat, Delft, erected in 1 day.
(130)	Iron One, Surrey, B.C. erected in 2 days.

5.3. Prefabrication of the entire building

The benefit of prefabrication may also apply to the other elements of the building system, envelope, mechanical and interior. Individually, each element can be made in an industrial environment with a greater control on cost, time and quality and shipped to the site for assembly. Further, the integration of the four elements (see *building system integration*) brings even greater benefits:

The structure provides a support for the fast and easy assembly of prefabricated floor decks, roofs. Wall panels and windows can be installed from inside.

The building can be closed and protected from the weather in a very short period of time, allowing the finishing works to start sooner and in controlled conditions. The end-product can be a fully functional, self-standing empty box that the owner can finish himself at his own pace. (see 2.5.)

The steel takes all the structural loads, except the primary wind load on the envelope.

The external walls can be made with light, economical prefabricated panels or glass walls attached to the structure. (See 3.6.)

The perimeter foundation walls are no longer necessary (see 2.2.)

The interior can be entirely opened or organized with light, pre-manufactured, sometimes movable, partitions or pre-manufactured cabinets. (See 2.4.)

The use of structural steel stimulates the prefabrication of the entire building. The result is a gain in quality, material and labour costs and speed of construction.

Despite the enormous advantages of prefabrication, the traditional method of building houses still prevails in most countries. Japan is an exception and produced 210,000 prefabricated houses per year or 14 percent of the 1.5 millions built per year. (IISI).

Some examples of Japanese prefabricated houses using structural steel are:

(146)	The SH Series house by Dr. Kenji Hirose. More than 90 house were built in the 1960s with an average cost for framing equal to 12.5percent of the total house.
(154)	More recently, Sekishui house Inc in Japan built 25,000 houses per year with structural steel and prefabricated panels.

The Sekishui company supplies and installs on a turn-key basis all the pre-manufactured elements of the building. It is an example of full integration provided by a single company.

In Europe, the best known example of an attempt to develop a prefabricated housing system is:

(99)	Patera system, by Richard Hopkins, Architect with Mark Whitby, Engineer. Two prototypes were built but the venture failed by lack of marketing and because it was a proprietary system that could not accept any third party building elements.

More successful was the Quadro-pod system because it could be assembled by hand and was an "open" system that could accommodate other building elements

(102)	Quadro-pod system by Gabriel Poole with Michael Gloster
(111)	Quadro-pod system by the same.

In North America, some companies are attempting to apply the Industrial / Commercial (IC) metal building technology to housing.

A interesting experiment with IC building technology was:

(125)	Parad Cohen house - or Topanga Canyon house, by Daly & Genik. The house uses the moment portal frame and galvanized steel panels of the Butler metal building system

6. Acceptability

6. 1. Large public interest

Steel houses presented as prototype very often raised an enormous public interest and steel house public exhibitions always attracted a great number of visitors. Examples of such popular steel houses are:

2	Dymaxion or 4-D house, by Buckminster Fuller, presented at the Marshall Field Exhibition, Chicago in 1927, raised an enormous interest with 3700 orders. The project sank because of lack of funds.
5	Lovell health house by Richard Neutra in Los Angeles. More than 10,000 visitors attended the open house.
9	Maison de verre by Pierre Chareau in Paris. 1932, is one of the most visited and published house in modern times.
10	House of Tomorrow by Fred Keck, presented at the 1933 Chicago exhibition, raised an enormous interest with more than 300,000 paying visitors during the exhibition.
11	Crystal house by Fred Keck, presented at the 1934 Chicago exhibition, raised a similar interest.
15	CSH # 8 by Charles & Ray Eames is frequently visited and widely published
154	Sekishui house built 25,000 prefabricated steel houses in Japan.

6.2. Support from the steel industry.

Bethlehem Steel supported one CSH and published the following five reasons to build with steel.

Table A2: Benefit of steel according to Bethleem Steel

Features -	Benefits
Free span.	Freedom of design.
No internal bearing wall	Dramatic possibilities.
Structurally sound.	Buildable on problem sites.
Prefabricated.	Cost same or cheaper than other methods.
Speed of building.	Reduce construction cost

US Steel (USS) supported the house "X-100" by Quincy Jones.

More recently, in 1995, the International Iron and Steel Institute (IISI) organized a seminar on "Steel in Housing," showing that the steel industry is now looking at housing as viable market for steel.

6.3. Design-built.

Notorious examples of steel houses designed and built by an architect are:

(9)	Maison de verre was the result of a collaborative work between the craftsman, Pierre Chareau, the architect Bernard Bijvoet and the locksmith Dalbet. There is no known plan of this house and it appears that most planning decisions were made during construction.
(20)	Olds house. Raphael Soriano could not find a builder to realize his ideas and was the contractor of most of his projects.
(36)	Eichler house developed by Quincy Jones for Eichler Company was open to the public and raised enormous interest.
(38)	X-100 by Quincy Jones also for Eichler as a prototype for mass housing. Open to the public, and visited by 250,000 persons.
(109)	Schmidt house. Edward Niles design-build all his houses because he could not find a contractor willing to undertake the construction at a reasonable price.
(117)	Sidley house by Edward Niles.
(126)	Ellis-Miller house. Ellis-Miller designed and built his own house.
(129)	McClymont house. McClymont designed and built his own house.

(133)	Clarke house #2. Chris Clarke designed and built this extension to his own house.

(136)	Wilen house by Ed Niles.

Table A1: Case Study Steel Houses

#	House	Architect / Designer / Engineer	Location	Year	Design Objective / Context	Characteristics	Outcome	References
1	Coventry Street Cottage	British Iron Foundry	Australia	1853	Early example of prefabricated steel house in Australia. Prefabricated in England, shipped to Australia.	Angle iron, column, top and bottom plates and corrugated galvanized cladding. Prefabrication.	Some houses are still in use today.	asac-p.122
2	Dymaxion or 4-D house.	Buckminster Fuller	Chicago	1927	Marshall Field Exhibition, Chicago. Mass production prototype.	Circular house built around a central mast. Economical and energy efficient. Prefabrication.	Despite an enormous public interest (3700 orders), the project sank because of a lack of funds.	msh-p.32
3	House 17	Walter Gropius	Stuttgard, Germany	1927	Weissenhofsiedlung experimental housing.	Experiment in prefabricated steel house.	Expensive, boxy, many problems during construction.	msh-p.25
4	Van der leeuw house	Cornelis van der Vlugt	Rotterdam, Holland	1929	Architectural approach, functionalism, international style.	Structural steel, modern house, first example in Europe, contemporary to Lovell.	First case of modern steel house in Europe.	msh-p.19
5	Lovell health house	Richard Neutra	Los Angeles	1929	Sloped lot, seismic zone, health clinic.	4" H columns, open web steel joists and prefabricated panels.	First case of structural steel house in US. Frequently published. Structure erected in 40 hrs.	msh-pp.3,11
6	BLPS	Jean Prouvé	Nancy. France	1930	Demountable, made with interchangeable parts.	Interlocking, double skinned pressed steel panels. Prefabrication.	Made and supported by Prouvé's factory.	msh-p.127
7	Aluminaire	Albert Frey	New York	1931	New York Exhibition. Experimental housing. Demountable.	Prefabricated aluminum and steel house.	The complete building erected in 10 days. Dismounted and re-erected as country house.	msh-p.27
8	A-Serien	Erik Friberger	Goteborg, Sweden	1932	Pavillion for an International Exhibition in Sweden. Experimental housing. Flexible plan, demountable.	H and I- sections, prefabricated panels.	Dismounted and re-erected as a house on a beach.	msh-p.30
9	Maison de verre	Pierre Chareau	Paris, France	1932	Infill of two lower stories in a 4 stories building.	Apparent composite steel column and glass blocks.	Landmark of modern architecture, steel and glass house.	msh-p.15

#	House	Architect / Designer / Engineer	Location	Year	Design Objective / Context	Characteristics	Outcome	References
10	House of Tomorrow	Fred Keck	Chicago	1933	Chicago exhibition. Experimental housing.	Double-decagon, central core, fully glazed walls. Prefabrication.	Enormous interest, more than 300,000 paying visitors during exhibition, frame erected in 48 hours.	msh-p.33
11	Crystal house	Fred Keck	Chicago	1934	Chicago exhibition. Experimental house. Glass and steel chosen as material that "go together rapidly and quickly" .	Light box., external structure in steel lattice, prefabricated.	Raised an enormous public interest.	msh-p.35
12	ARCON	Carl Koch	U.K.	1940	Temporary construction.	Lightweight construction with corrugated galvanized cladding.	Rather basic shelter.	msh-p.128
13	Katz house	Raphael Soriano	Van Nuys	1947	Built for a private client with a low budget.	I beam, lattis (proprietary open web) steel joists, steel pipe columns. Prefabrication.	Low cost house.	msh-p.56
14	Lyndon house	Maynard Lyndon	Malibu, Ca	1948	Modem house.	Exposed steel.	Re-modeled by Ed Niles bought by Alvin Toffler.	msh-p.210
15	Case Study # 8	Charles and Ray Eames	Los Angeles	1949	Case study house program of "Arts and Architecture". use of prefabricated industrial elements.	Exposed steel structure with open web joist. Infill standard industrial sashes and panels. Prefabrication.	Open, airy, pleasant working, living space. Large influence on modem architecture.	msh-p.51 csh-p.54 tca-p.170
16	Metropole house	Jean Prouvé	France	1949	Post war housing crisis	Axial portal frame and ridge beam. Post-tensed curved roof panel, lightweight wall panels. Prefabrication.	Fast construction. 25 houses built.	PC-p.46
17	Glass house	Philip Johnson	New Canaan, Connecticut.	1949	Modernist approach. Steel and glass house.	Open plan, steel and glass.	Landmark of modem architecture. Frequently published project.	msh-p.75
18	Case Study # 9. Entenza house	Eero Saarinen, Charles Eames	Los Angeles	1950	Case study house program of "Arts and Architecture". Experimental house to demonstrate the efficacy of modular, lightweight construction.	Concealed steel structure, open plan. Prefabrication.	Open, airy, pleasant working and living space. Large influence on modem architecture.	msh-p.51 csh-p.54 tca-p.170
19	War Service house	Hawkins and Sand	Australia	1950	Economical house erected quickly to a good design.	Lightweight.	Basic design for war period.	msh-p.129

#	House	Architect / Designer / Engineer	Location	Year	Design Objective / Context	Characteristics	Outcome	References
20	Olds house	Raphael Soriano	Pacific Palisade, Los Angeles	1950	Case study house program of "Arts and Architecture.".	3.5 " pipe column, 10 by 20 foot structural steel bay. Modular steel construction, open plan. Cabinets form walls. Prefabrication.	architect was the contractor.	msh-p.62
21	Shulman house	Raphael Soriano	Los Angeles	1950	Built for a Julius Shulman, phographer and admirer of the case study house program.	I beam, steel pipe column, wood wall and roof. Internal walls made with cabinets. Prefabrication.	5 % more expensive than wood.	msh-p.59
22	Curtis house	Raphael Soriano	Los Angeles	1950	Experimental house for a private client. Factory-based approach. A flexible space under a steel umbrella.	Open-Flexible plans. Entirely prefabricated. All metal house. I beam, steel pipe column. Internal walls made with cabinets.	Frame erected in one day.	msh-p.60
23	Tropical house	Jean Prouvé	Niamey. Niger.	1951	Prototype for manufactured housing in tropical setting. Demountable.	Axial portal frame and ridge beam. Curved roof panel. Double roof for ventilation. Prefabrication.	Transported by plane. Low cost housing. Fast assembly.	PC-p.152
24	Farnsworth house	Mies van der Rohe	Plan, Illinois,	1951	Modernist approach.	Welded in place I beams and columns. Glazed external walls. Open plan.	Landmark of modern architecture. Cost higher than budgeted.	msh-p.66
25	Prefabricated Hut	Eric Leach	Australia	1952	Light and economical.	Galvanized tubular steel and corrugated sheeting.	Flexible and lightweight.	msh-p.134
26	Case Study #16. Salzman house	Craig Ellwood	Los Angeles	1953	Case study house program of "Arts and Architecture".	HSS columns, I beams, welde, 8' module. Infill panels. Prefabrication.	Simple and minimalist.	msh-p.88
27	Maison Prouvé	Jean Prouvé	Nancy. France	1953	Own house. Use of prefabricated steel elements from Prouvé's steel factory.	Lightweight frames. Interlocking, double skinned pressed steel panels. Prefabrication.	Collage of components. Recycled material. Low cost.	msh-p.127
28	Turramura	Harry Seidler	Australia	1954	Suspended over steep slope.	Double cantilever steel bridge.	Rational and visually tantalizing.	msh-p.135
29	Jones house	Quincy Jones	Los Angeles	1954	Own house. Investigate cost vs. wood.	Open plan. Q deck roof. I beams. Infill glass walls and panels.	Same cost as wood. Fast assembly.	msh-p.77
30	Richardson house	Robin Boyd	Australia	1954	Suspended over a gully. Steep slope.	Bow string lattice truss.	Hidden in a private garden.	msh-p.135
31	Case Study #17. Hoffman house	Craig Ellwood	Beverly hills, Los Angeles	1955	Case study house program of "Arts and Architecture".	4" H columns, I beams, 8' module. Hollow clay brick infill. Prefabrication.	Re-decorated beyond recognition afterwards.	msh-p.88
32	Smith house	Craig Ellwood	Los Angeles	1955	Built on a steep hill.	Light steel.	Promoted by Bethleem steel.	msh-p.203

#	House	Architect / Designer / Engineer	Location	Year	Design Objective / Context	Characteristics	Outcome	References
33	Mcintyre house	Peter Mcintyre	Australia	1955	Suspended over steep slope. Raising house over a 9 m high river flood level.	"A" frame. Prefabrication.	Raised enormous interest.	msh-p.135
34	Hunter/McKim house	Peter Parkinson	Australia	1955	Case study in Australia. Experimental steel frame house. In architectural practice of Hawkins and Sand. Craig Ellwood influence.	Thin pipe columns, cross bracing, open-web trusses. Prefabrication.	Sits lightly on the site.	msh-p.129
35	US Gypsum Research house	Quincy Jones	Barrington, Illinois.	1955	Experimental house for mass production. Built for US Gypsum research Village in Barrington.	Open plan, Q deck roof, I beams, open web steel joist, lightweight gypsum lath partitions.	Low cost housing solution.	msh-p.80
36	Eichler house	Quincy Jones	Los Angeles	1955	Experiment to gain cost and production experience on the use of steel for mass-production building.	H column and I beams, Factory-made storage walls. Infill glass walls and panels. Prefabrication.	Frame erected in 2.5 hours. When finished open to the public. Raised great interest.	msh-p.82
37	Russel William house	John Bish	Australia	1956	Case study in Australia. Craig Ellwood influence. Experimental steel frame house.	Thin pipe columns, cross bracing, open-web trusses. Prefabrication.	Sits lightly on the site. Light Foundation.	msh-p.129
38	X-100	Quincy Jones	San Mateo	1956	Experiment to gain cost and production experience on the use of steel for mass-production building.	H columns, I beams, Q-deck roof. Infill glass walls and panels. Prefabrication.	Open to the public, visited by 250,000 persons. Fast assembly.	msh-p.83
39	Own house	Bill Lucas	Australia	1957	Light and economical.	Lightweight, glass and corrugated metal roof.	.	msh-p.134
40	Sands house	Bob Stafford	Australia	1957	Case study in Australia. Craig Ellwood influence. Experimental steel frame house.	Thin pipe columns, cross bracing, open-web trusses. Prefabrication.	sits lightly on the site. Light foundation.	msh-p.129
41	Panshanger	Michael Newberry	U.K.	1957	Experimental house to show possibilities of exposed steel.	Reciprocal frame. Off-center columns. Glass house. Prefabrication.	Some glass walls coverd by new owners.	msh-p.136
42	Case Study #18. Fields house	Craig Ellwood	Beverly hills, Los Angeles	1958	Case study house program of "Arts and Architecture".	2" HSS columns, 2x 5 1/2 tube beams, 8' module. Pre-welded. Prefabrication Infill panels.	Pre-welded portal frame transported to the site. Bethlehem steel advertised the house.	msh-p.94

#	House	Architect / Designer / Engineer	Location	Year	Design Objective / Context	Characteristics	Outcome	References
43	Bingie farm	Glenn Murcutt	Australia	1958	Integration into the Australian landscape. It creates indoor - outdoor relationship.	Prefabricated. Soft, curved steel, corrugated metal roof, canopy.	Lightness, touches the ground lightly. Frequently published steel house.	msh-p.174 asac-p.224
44	Saharan Habitat	Jean Prouvé	France	1958	Prototype of manufactured house for desert dwelling.	Axial portal frame, ridge beam and curved roof panel as umbrella. Prefabrication.	Low cost. Fast assembly.	PC-p.148
45	Case Study #21. Bailey house	Pierre Koenig	Los Angeles	1958	Case study house program of "Arts and Architecture". Experiment on industrialized mass production potential of steel-frame construction.	H columns, I beams, Glass walls, Q-deck roof. Infill panels. Prefabrication.	Surrounded by pools, summer cooling, water circulation on the roof.	msh-p.98
46	Case Study #22. Stahl house	Pierre Koenig	Los Angeles	1958	Case study house program of "Arts and Architecture". Steep slope. Eagle nest view lot.	H columns, I beams, welded connections, infill glass walls and panels, Q-deck roof. Prefabrication.	Economically built.	msh-p.99
47	Coal and steel Community	Renzo Zavanala	Brussels, Belgium	1958	Pavilion for Expo 58.	Sheet steel panels, trussed pitched roof,. Prefabrication.	Fit like a meccano set.	msh-p.206
48	Branch Lane house	Peter Stead	U.K.	1959	Steep hill.	Hidden frame.	.	msh-p.203
49	Daphne house	Craig Ellwood	Hillsborough, San Francisco.	1960	Modem, Mies influence.	H eccentric column, I beam.	Steel house defined as a style and architectural language.	msh-p.102
50	IDL System	Depelsenaire-Lesage	Belgium	1960	Prototype for manufactured housing.	Prefabrication. Steel enamel infill panel, aluminum framed infill windows, aluminum roof.	Complete house built in 13 weeks.	msh-p.206
51	SCSD System	Ezra Ehrenkrantz	California	1960	Development of standard and compatible building components.	4 basic elements: structure (steel), mechanical, lighting, partitions. Prefabrication.	System Building.	msh-p.110
52	DEW Line project	Pierre Koenig	Canada	1960	Prefabricated house for Canadian North.	Artic sheet-steel thermal insulating panels. Prefabrication.	Boxy houses.	msh-p.206
53	Levi house	Anthony Bernard Levy	U.K.	1961	Steep hill. Mies influence. style.	Heavy steel.	Do not achieve lightness and simplicity.	msh-p.204
54	Rosen house	Craig Ellwood	Brentwood, L.A	1961	Modem, Mies influence.	H column, I beam.	Steel house defined as a style.	msh-p.102
55	Pierson guest house, addition.	Craig Ellwood	Malibu.	1969	Addition to 1953 house in malibu.	H column, I beam, welded. Bridge house.	Steel house defined as a style and architectural language.	msh-p.102
56	The Combee	Geoffrey Summerhayes	Australia	1961	Marcel Breuer influence. hillside building.	Steel in the roof. Open flexible plan. Brick-faced walls.	Simple elegant, open ended white box.	msh-p.132

#	House	Architect / Designer / Engineer	Location	Year	Design Objective / Context	Characteristics	Outcome	References
57	Parents' house at Millspond	Kenneth Klaxton	U.K.	1961	Steep hill.	Glass box.	Do not achieve lightness and simplicity.	msh-p.204
58	House on a cliff	Masahiro Chatani	Japan	1961	Steep hill.	Inverted triangle frame of heavy steel. Lightweight structure.	Lightness.	msh-p.204
59	Cliffhanger	Michael Manser, architect and Jack Dawson, engineer.	U.K.	1961	Hanging house on a 45 deg. slope.	Prefabricated building elements assembled like a meccano.	engineering response to steepness of the site.	msh-p.141
60	Alsmonbury house	Peter Stead	U.K.	1962	Steep hill.	Hidden frame.	Fail to express the logic of steel.	msh-p.203
61	Frey house	Albert Frey	Palm Spring. Ca	1964	Own house, low budget, modernist approach.	Lightweight, boulder inside-outside, corrugated corten roof, acoustic metal ceiling (in blue).	"House in the desert.".	msh-p.215
62	Richards house	Duncan Richards	Australia	1965	Research on benefit of steel vs wood. "Steel more economical and more reliable than timber and available in 20 ft. length"	Lightweight, cold formed steel.	Price comparable to wood.	msh-p.132
63	Steward-Ross house	John Winter	Surrey. U.K.	1965	Quick construction so client can finish himself, protected from the weather.	Square box. section and I beams.	House beneath a canopy. Fast assembly.	msh-p.138
64	Buckland Cop	Michael Manser, architect and Jack Dawson, engineer.	U.K.	1966	Flexible, open, quick, precise and relatively economical.	Prefabricated building elements assembled like a meccano. Open plan	Relatively economical. Fast assembly.	msh-p.141
65	Forest Lodge	Michael Manser, architect and Jack Dawson, engineer.	U.K.	1967	Flexible, open, quick, precise and relatively economical.	Prefabricated building elements assembled like a meccano. Open plan	Relatively economical. Fast assembly.	msh-p.141
66	Winter house	John Winter	U.K.	1968	Chicago style, modern steel house.	Welded I beams, (same as Mies), welded skin in corten.	"Climbing plants do not like Corten steel"	msh-p.138
67	Spender house	Richard and Sue Rogers. Architects. Tony Hunt, Engineer.	U.K.	1968	Precision, lightness, clear span, free-form planning. Economical.	Linear extrusion. Factory finished catalog components.	Low cost. A free standing house, separate studio, courtyard for £ 12,500 (or CAD$ 25,000) .	msh-p.144
68	Pavlevsky house	Craig Ellwood	Palm Spring,	1969	Modern steel house. Steel house defined as a style and architectural language.	No data available.	Craig Elwood's last steel house	msh-p.110

#	House	Architect / Designer / Engineer	Location	Year	Design Objective / Context	Characteristics	Outcome	References
69	Field house	Georgie Wolton	Surrey, U.K.	1969	Mies influence.	External Cor-ten structural steel.	Now dismantled and in storage, has completed its first life and awaits another.	msh-p.148
70	Roger house	Richard and Sue Rogers, John Young, architects. Tony Hunt, Engineer.	Wimbledon, U.K.	1969	Own house. Modernist approach. Light and low-budget. Eameses influence.	Portal frame, envelope made with refrigerated truck panels. Prefabrication.	Economically built. Structural simplicity.	msh-p.146
71	DC pine house	Robin Spence	U.K.	1969	Designed to be extended by adding extra bays.	24 ft portal frame with I sections. Open flexible plan.	Demolished.	msh-p.152
72	Hopkins house	Michael and Patti Hopkins Tony Hunt, Engineer.	Hampstead, U.K.	1970	Own house, Eames influence, open plan.	Steel and Glass box. Square column, open web Joist, corrugated Deck. 4 x 2 m grid.	Owner moved in before interior finished. Plan evoluated with family needs.	msh-p.161
73	Capel Manor	Michael Manser, architect and Jack Dawson, engineer.	U.K.	1970	Flexible, open, quick, precise and relatively economical.	Prefabricated building elements assembled like a meccano. Open plan. Glass house.	Relatively economical. Fast assembly. "owner enthusiastic"	msh-p.142
74	Talon house	Ronnie talon	Dublin	1970	Chicago style. Own house.	Exposed steel structure.	Expanded later on.	msh-p.153
75	Mozin house	J. Mozin	Liege. Belgium	1971	Hillside building.	No data available.	No data available.	msh-p.203
76	Murray Harvey	Robin Spence	U.K.	1971	Chicago style.	Exposed steel structure, large span.	Occupied by same owner for 25 years. "everyone who come s into this bungalow admires it."	msh-p.152
77	Fombertaux house	J. Fombertaux	Lindfield, Australia	1972	Own house. Modern approach.	3"x3" column, 8" and 6" channels, Infill walls panels.	Exposed structure in and out.	asac-p.196
78	Laurie Short house	Glenn Murcutt	Terren hills. Australia	1973	Philip Johnson alike.	Steel and Glass Pavilion. External steel frame. Eccentric column. Open plan	High energy consumer house.	msh-p.159 asac-p.198
79	System Cube	Masuyaki Kurokawa	Japan	1973	Building System with cubes.	8'x8'x8' Module with 3" angle channel. + plywood sheet and insulation.	.	msh-p.222
80	Goulding Studio	Ronnie Talon	Ireland	1973	Steep hill.	Truss + Rock anchor + cedar siding.	Bridge house. Assembled by owner.	msh-p.203

#	House	Architect / Designer / Engineer	Location	Year	Design Objective / Context	Characteristics	Outcome	References
81	Brumwell house	Alan Colquhoun and John Miller, Tony Hunt, Engineer	Pill Creek, Cornwall, U.K.	1974	Steep hill.	Circular steel column with branching supports. GRP insulated panels.	Lightness.	msh-p.204
82	Mancett house	Michael Manser, architect and Jack Dawson, engineer.	U.K.	1974	Flexible, open, quick, precise and relatively economical.	Prefabricated building elements assembled like a meccano. Open plan	Relatively economical. Fast assembly.	msh-p.141
83	Branksome Park	Richard Horden	U.K.	1975	Chicago style and Craig Ellwood.	3x 33 feet bays.	.	msh-p.155
84	Euladan house or house at Bayview	Richard LePlastrier	Sydney, Australia	1975	Integration into Australia landscape.	Soft, curved steel, portal frame, corrugated metal roof. Prefabrication.	Lightness, "touch the ground lightly".	msh-p.171 asac-p.214
85	Schulitz house	Helmut Schulitz	Ca.	1976	Own house. Prototype for hillside building. Experimental system building.	Standard building components, W beam, open web joist, square tube column. Prefabrication.	One-off example of a prototype.	msh-p.111
86	Van Den Bosshe house	Ian Ritchie. Tony Hunt, Engineer	Amiens, France.	1976	California, open plan.	Small grid. Prefabrication. Open plan	Low cost. Built for £15,500 equivalent to CAD $30,000.	msh-p.162
87	de Breteville house	Pierre de Breteville house	Los Angeles	1976	Long span.	Industrial components. Prefabrication.	System Building.	msh-p.112
88	Architect's Bill house	Remo Bill	Grenchen, Switzerland	1976	Originally was designed for an exhibition pavilion,	USM-Haller mini steel framing system. Tubular column, I beam with holes, Meccano-type, Demountable. Prefabrication.	Fast assembly. Became showroom with an office, and finally a house.	IISI-13
89	Robinson house	Noel Robinson	Brisbane, Australia.	1977	House for the parents.	Welded Tubular steel.	"small but spacially generous"	asac-p.207
90	Wedgwood	Peter Aldington	U.K.	1977	Chicago style. Similar to Farnswood house by Mies van der Rohe.	2 rows of 4 H columns, eccentric.	owner cannot imagine living in any other type of house. Small but generous in usable space.	msh-p.150
91	Ark Ockens house	Glenn Murcutt	Cromer. Australia	1978	Modernism.	Round tube column, W Beam, externally exposed. Glazed roof.	Rooms around an internal courtyard.	asac-p.199
92	Wave house	Morrice Shaw	Sydney, Australia	1979	Metaphor of a wave.	75 mm pre-welded tubular frame in barrel vault. Linear extrusion of portal frames. Prefabrication.	Sculptural, wave-looking house.	asac-p.212

#	House	Architect / Designer / Engineer	Location	Year	Design Objective / Context	Characteristics	Outcome	References
93	Hardy house	Chris Clarke, John Winter	London. U.K.	1980	British hi-tech.	Double cantilever.	House suspended to a V structure.	msh-p.182
94	Andrews Farm house	John Andrews	Eugowra, Australia.	1980	Experimental, ex-catalogue, prefabricated house for rural zone.	Welded frame, prefabricated and transported to the site. Corrugated sheet metal.	.	asac-p.200
95	Butterfly house	Shoei Yoh	Japan	1980	Butterfly metaphor.	Stainless steel.	Sculptural house.	msh-p.211
96	Koganei house	Toyo Ito	Japan	1980	Similar to John Winter house. (Chicago style).	Angle and C Channel, self supporting profile metal roof.	Tatami house.	msh-p.222
97	Spence/Webster house	Robin Spence and Robin Webster Tony Hunt, Engineer	London, U.K.	1981	Courtyard, double house.	Steel and glass box. Movable partitions. Prefabrication.	Steel and glass box.	msh-p.169
98	Eagle Rock	Ian Ritchie	U.K.	1982	Hi-tech. Application of Richard Rogers industrial building to housing. Eagle symbol.	Steel post and cables.	Oversized columns. Example of how scale effect modify house proportions.	msh-p.164
99	Patera System	Richard Hopkins, Architect. Mark Whitby, Engineer.	U.K.	1982	Pre-fabrication. Experimental building system.	External space frame and panels. "Closed" system. Prefabrication.	2 prototypes built, failed by lack of marketing and because it was a "closed" system. Fast assembly.	msh-p.189
100	Ball-Eastway	Glenn Murcutt	Australia	1983	Integration in the Australian landscape.	Soft, curved steel, corrugated metal roof. External sprinkler for bush fire. Prefabrication.	Lightness, "touches the ground lightly".	msh-p.173 asac-p.220
101	Mackeral Beach house	Allen, Jack and Cottier.	Sydney, Australia.	1984	Week-end house. No road access.	100 HSS, Wood beam, Corrugated panels. Prefabrication.	Example of steel used where there is no road access. Fast assembly.	asac-p.200
102	Gloster house	Gabriel Poole with Michael Gloster	Queensland, Australia	1984	Experimental, originally designed as low-cost housing for South-East Asia. Demountable.	Quadro-Pod System, "open" system, modular 3x3 m or 3x 3.6 m. Assembled without a crane, Walls be could assembled from inside building. (No scaffolding). Prefabrication.	Example of "open" system. lightness, few points touching the ground, minimal footings. Low cost. Market success. Fast assembly.	asac-p.222
103	Yacht house	Richard Horden	Hampshire, U.K.	1984	Technology transfer for ship construction.	Metal mast. Lightweight. Demountable. 12 ft modules. Prefabrication.	Frame erected in 5 hours.	msh-p.186
104	Silver Hut	Toyo Ito	Japan	1984	Own house, architectural approach.	Lightweight steel structure.	Well-published house.	msh-p.222

#	House	Architect / Designer / Engineer	Location	Year	Design Objective / Context	Characteristics	Outcome	References
105	Clarke house	Chris Clarke Mark Whitby, Engineer.	Australia	1985	Steep hill, British Hi-Tech in Australia.	Double cantilever steel bridge. 3 ft square grid.	Frame erected in 8 hours.	msh-p.182
106	Hoffman house	Ed Duc	Bilgola, Australia	1985	Eames influence. Designed to be assembled by owner. System building approach.	Kit of parts. 2.5"x2.5" HSS, 12" beam. Top Angle. Q-deck, steel FR. panels. Prefabrication.	Assembled in 4 days. Finished by owner. Low cost.	asac-p.200
107	Frishknecht house	Paul Frishknecht Ove Arup, Engineers.	Australia	1985	Steep hill, open, flexible, recyclable.	Four storey steel frame. External frame made with 140 mm round HSS, eccentric. Prefabrication. Open plan	Frame erected in 3 days.	msh-p.179 asac-p.204
108	House in Magomezawa	Toyo Ito	Tokyo, Japan	1985	Architectural approach.	Lightweight steel structure. Dome vault, Zinc aluminum panels.	high-tech and primitive.	msh-p.222
109	Schmidt house	Edward Niles	Malibu, Ca	1986	Remodeling for the futurist Alvin Toffler.	Steel and Glass house.	Originally built by Maynard Lyndon.	msh-p.210
110	Kayo house	Hisao Kay	Japan	1986	Traditional timber frame made in steel.	Bolted steel sections and tension rods.	Tatami house.	msh-p.222
111	David and Pam Noble house	Gabriel Poole	Australia	1987	Experimental, Quadro-Pod system. To provide maximum living area for the minimum site disturbance.	Open system,can be assembled by hand. Prefabrication.	Lightness, few points touching the ground. Assembled without a crane. Fast assembly. Open system.	msh-p.190
112	Jourda-Perraudin house	Jourda-Perraudin	Lyon, France	1987	Own house. Low budget. Canopy over wooden box.	Exposed plywood box under an umbrella made with steel frame and fabric.	Garden Pavilion, Minimalist. Economical to built.	msh-p.216
113	McCorkell farmhouse	Peter Elliott	Australia	1987	Metal Shed. Low budget.	Curved open web trusses. Prefabrication.	Low cost.	msh-p.177
114	House in Takagi-Cho	Toyo Ito	Japan	1988	Architectural approach.	Lightweight steel Structure.	Well-published house.	msh-p.222
115	Platform house I	Toyo Ito	Japan	1988	Architectural approach.	Lightweight steel Structure.	Transparent walls.	msh-p.222
116	Platform house II	Toyo Ito	Japan	1988	Architectural approach.	Lightweight steel Structure.	Transparent walls.	msh-p.222
117	Sidley house	Edward Niles	Malibu, Ca	1989	Technological solution to a living problem. Honesty, sustainability, new age.	Curved steel. Solar panels. Linear extrusion.	Exposed steel and services. The architect was the contractor.	msh-p.209
118	Housing Project	Brian McKay-Lyons	Halifax, Canada	1990	Prototype in the context of semi-industrial neighborhood.	???	Low Cost, Cad$580/m2 = $54/ft2	CA-June 1990
119	Pesman house	CEPEZED	Holland	1990	Manifest against the "traveling factory".	Pipe columns + I beams. Insulated stainless steel panels. Prefabrication.	Frame erected in one day.	msh-p.192

#	House	Architect / Designer / Engineer	Location	Year	Design Objective / Context	Characteristics	Outcome	References
120	3, Schuterstraat, Delft.	CEPEZED	Delft, Holland	1990	Pre-fabrication. Experimental housing program. "Steel is a very rational way of building".	Pipe columns + I beams + Cladding and industrial components. Prefabrication.	Frame erected in one day. The fastest building in a serie of experimental housing program.	msh-p.192 iisi-p.17
121	House in Portland	David Rockwood	Portland, Oregon,.	1990	Modernist approach.	Welded steel frame. Glass box.	High status house.	Ad-p. 204
122	Maurios house	Georges Maurios	Paris, France	1990	Own house, rooftop addition to an old villa. Weight restriction.	Round tube column, W-beam, Q-deck. Prefabrication.	Light addition to existing house in downtown Paris.	HotA-p.104
123	Maison/Pharmacie Gentil	Ian Ritchie	Amiens, France	1990	Pre-fabrication. Very low budget.	Pipes, curved steel.	Design and project management by fax. Montage "a blanc" in France.	msh-p.193
124	Newman house	James Grose	Australia	1990	Praying mantis metaphor. Designed to be unbolt and taken away. Glenn Murcutt influence.	Exposed steel. Corrugated steel, industrial components and industrial waste. (bed of steel slag).	Sculptural steel house.	msh-p.212
125	Parad Cohen house	Daly and Genik	Los Angeles	1991	Experimental housing.	Industrial and agricultural prefabricated building. Galvanized steel cladding and portal frame of Butler system.	Application of industrial, agricultural metal "Butler" system to housing.	msh-p.206
126	Ellis-Miller house	Ellis-Miller	Ely. U.K.	1991	Own house.	External I beams 10x4 beam, 4x4 column.	Architect was the contractor.	msh-p.218. IISI p.13
127	Stinton house	Jeffrey Stinton	Toronto, Canada	1991	Own house.	Curved roof with heavy corrugated steel shell.	.	CA-Ap.94
128	Winter house	John Winter Mark Whitby Engineer.	Norfolk, U.K.	1991	Own house, low budget, holiday house.	Angle and C Channel, self supporting profile metal roof.	The architect had to fight two years to obtain a building permit.	msh-p.217
129	McClymont house	McClymont Mark Whitby Engineer.	Scotland	1991	Own house. Very low budget.	Hand manageable length of steel. 4"x4"x11' column and cold formed 12' purlins. No cold bridging. 10" wall insulation, 12" roof insulation. removable floor system with heating.	McClymont built himself. Hand manageable steel elements.	msh-p.220
130	Iron One	Michel de Spot	Surrey, B.C. Canada	1991	Experimental. cost vs. wood. Large windows, passive solar system. Engineering approach to housing.	4"x4" HSS. W8 beams, W6 joist. Q-deck. Prefabrication.	Erected in 2 days. Cost similar to wood. Built by owner / engineer.	Personal File

#	House	Architect / Designer / Engineer	Location	Year	Design Objective / Context	Characteristics	Outcome	References
131	Shoei Yoh house	Shoei Yoh	Japan	1991	Own house, Steep hill.	Steel concrete glass.	Glass box.	HotA-p.180
132	McKenzie house	Chris Clarke	Australia	1992	Steep hill.	Double cantilever. Use of light cold-formed steel and structural tubes.	Light. Touches ground in a few points.	msh-p.183
133	Clarke house #2	Chris Clarke	Australia	1992	Extension of own house on steep hill. Modernist approach.	Light enough to be manhandled. Cold formed C and Z made with high tensile steel stronger than hot rolled profiles.	Steel and glass with standard windows. Built by the architect.	msh-p.183
134	House	Kasanski	Port Lincoln, Australia	1992	Australian traditional house with steel frame.	Prefabrication.	No data available.	SISC-23
135	O'Connor house	Ronnie talon	Ireland	1992	Hillside building.	Brick walls, steel, glass.	T-shaped.	msh-p.203
136	Wilen house	Edward Niles. Dimitri Vergun, Norm Epstein Engineers	Santa Monica	1993	Technological solution to a living problem.	Curved steel, chrome, stainless steel. Linear extrusion of curved frames.	Metaphorical house. The architect was the contractor.	msh-p.206
137	Hauer/King house	Future System	London. U.K.	1994	Technology transfer of industrial components to housing. Chareau's influence.	Full integration of components. Prefabrication.Glass blocks. Glass panels wrapping the building.	Functionality and structure.	msh-p.185
138	Schwartz house	Pierre Koenig	Pacific Palisades. Ca.	1994	Steep hill.	Double Frame. One suspended in the other.	Two-frames-in-one. Pierre Koenig's most recent steel house.	msh-p.205
139	Home in Belair	Rick Bzowy	St. Kilda, Victoria. Australia.	1994	Functional and minimalist, open plan, small budget.	200 mm C Channels. Open plan	Cost CAD$ 130,000. Fast assembly.	IISI-15
140	Graham/Angell house	Sarah Graham and Mark Angell.	Los Angeles	1994	Experimental steel house.	I beam and columns.	Driven by process over product.	msh-p.206
141	Stanley Terrace house	John Schnier and John Potter	Toronto, Canada	1995	Small lot, structure to cantilever garage.	.	Flexibility.	CA-Dec.94
142	House Psyche	Rene van Zuuk.	Almere. Holland	1995	"De Fantasie" experimental housing program.	Cantilever welded central support Y shapes cantilever beam-column.	Sculptural steel house.	IISI-14
143	Daiwa prefabricated house.	Daiwa house Inc.	Osaka, Japan	1996	Mass produced housing. steel structure answer to seismic requirements.	HSS column W beam, prefabricated panel.	Japan has 1.5 million housing per year, 14.4% are prefabricated.	IISI-9
144	La Viuica housing system	Jose Ora	Venezuela	1996	Difficult site, cost saving in excavation.	Welded HSS.	Hollow frame receive service. Low cost.	IISI-11
145	Decra project	Rubi Slabbinck.	Belgium	1996	Flexible house prototype.	HSS column and beam.	.	iiSI-8

#	House	Architect / Designer / Engineer	Location	Year	Design Objective / Context	Characteristics	Outcome	References
146	SH Series house	Dr. Kenji Hirose	Japan	196x	Post-war housing shortage.	2 C channel to make for 100x100 column similar to Japanese wood post. Prefabrication.	More than 90 built. Average cost for framing is 12.5% of total house. Fast assembly.	SIH-30
147	Hafter house	Fritz Haller	Switzerland	198x	Modern, prefabricated.	HSS, castelated beam. Prefabrication.	.	SISC-15
148	House	Itsuko Hasegawa	Japan	199x	Metaphorical	Curved beam, Q Decking.	.	SISC-15
149	Family house	Jacobs	Belgium	199x	prefabricated.	I beam and columns, steel panels. Prefabrication.	.	
150	House in Minamisuna	Kazuhito Namba	Minamisuna, Japan	199x	Reduction in foundation loads, seismic resistance.	W 150x150mm, 90mm HSS, rod bracing. Floating foundation. Prefabrication.	Fast assembly.	IISI-18
151	River View house	Kyunk Kook Woo	Seoul	199x	River metaphor.	Column. H 200x200, beam W 150x200. Linear "extrusion" of portal frames.	Sculptural, upper-scale house.	IISI-20
152	Jungerhalde house	Martin Cleffmann	Konstanz, Germany	1995	Low budget housing program.	Column H 100, beam UNP 120, larch floor planks on steel joist. Open-flexible layout. Lightweight building components. Prefabrication.	Example of application of steel to low-cost urban housing. Fast assembly.	IISI-24
153	Pritchard's house	Max Pritchard	Adelaide, Australia	199x	Difficult foundation. Steep hill.	4 foundation piers only, double cantilever. and 15 m central span.	Fast assembly.	IISI-16
154	Sekishui house	Sekishui house Inc.	Japan	199x	Prefabricated housing program.	Steel Structure: HSS 57x3.2, beam H 200x100 and Wall in C 60x30 (metric). Prefabrication.	25,000 prefabricated houses built per year. Fast assembly.	SIH-114
155	House in Rekem	Swinkels Passchier	Rekem, Belgium	199x	Marsh site, pile foundation.	2xC160 with insulation, infill panel, glass, wooden joist. Prefabrication.	House in a marsh.	IISI-20
156	House in Shimogamo	Waro Kishi	Shimogamo, Japan	199x	Traditional Japanese order.	W244 beam, H175 column, rod bracing.	Traditional Japanese tatami house in steel.	IISI-19
157	Eppich house	Arthur Erickson	West Vancouver, B.C. Canada.	199x	Metaphor of steel and fire.	Exposed. C channel welded face-to-face, glass panels and glass Blocks inserted in the frame, chromed columns.	Owner had difficulty finding reasonable contractor prices and had to be his own contractor.	Personal file

#	House	Architect / Designer / Engineer	Location	Year	Design Objective / Context	Characteristics	Outcome	References
158	Residence Mercille	Saucier, Perrotte	St Madeleine de Drigaud, Quebec	1996	Metaphorical.			CA-Feb.96
159	Maison du mecanicien	Olivier Noterman	Brussels, Belgium	1998	Steel and glass addition to existing old villa.	I beams, Q-decks, Reglite	Owners are extremly proud and happy	Personal files

References

msh	The Modern Steel House.
iisi	International Institute of Steel Industry
asac	Architecture in Steel the Australian Context.
pc	Prouve Cours du CNAM
sih	Steel in Housing
sisc	Swedish Institute of Steel Construction
ca	Canadian Architect
csh	Case Study House
tca	Twentieth Century Architecture
hota	The House of the Architect

Appendix B – FAQ on Steel Houses.

Here follows a list based on frequently asked questions by builders and home-owner to the AISI about steel in housing:

Q Why build with steel?

A *Steel is cost effective, manufactured under strict quality standard. Compared to wood, steel is termite- and rot- proof, non-combustible and durable.*

Q What are the advantages for builders?

A *Steel is ideal for pre-fabrication. It is a stable material and contrary to wood, the price of steel has not changed significantly over the years. Steel scrap has a value and can be recycled.*

Q Will the house look different from the rest of my neighborhood?

A *Only if you want. Because steel is stronger, house can be designed with larger open space.*

Q What about the environmental impact of steel construction.?

A *Overall recycling rate of the industry is 66% the highest of any industry in North America. Steel is environmentally sound and sustainable.*

Q What about cost?

A *Building with steel is commonly less expensive than traditional wood framing. The price of steel has been relatively constant over the last decade. While the price of wood has been erratic and growing at rate much faster than inflation.*

Q Can I find competent steel contractors?

A *Steel contractors have demonstrated their competence for many years in commercial and multi-family construction. In addition, precision engineering and new tools have simplified steel construction*

Q Will the house need bigger footings and foundations?

A *A steel structure house weight 2.25 times less than wood framing components with similar strength. The foundation and even the seismic load can be smaller.*

Q Can I find plumbers and electricians to work on the house?

A *Plumbers and electricians have worked with steel framing in commercial construction for years and are very familiar with it.*

Q Is steel readily available?

A *Structural steel components are available from coast to coast in bulk, in pre-cut length or pre-engineered building systems.*

Q Can I build steel framed home close to the seashore?

A *As required for any home construction, a standard weather barrier protects all the steel.*

Q Will I be able to sell my house?

A *A steel house does not need to look different from the neighbor's and should sell just as easily. The strength of steel allows to design of wide-open space and increases the flexibility of living space. Because of steel strength and durability, the house will last* *longer and retail its value for a longer time. Flexibility and strength are additional selling value.*

Q Can my home be energy efficient?

A *The steel frame is inside an envelope and the house can be designed to meet or exceed energy efficiency standard. No structural element in the wall bridge the cold weather. In addition, the curtain wall does not crack, shrink or warp, thus preventing air leaks that results in costly loss of energy.*

Q Will the steel frame interfere with portable radios, phones, or TV reception.

A *Waves pass through the space between steel frame allowing the use of all the radios, phones and television sets in your home.*

Q What about lightning?

A *The steel frame offers the home occupants better protection than any other construction system.*

Q Will my home rust?

A *Steel is inside and protected from the weather. The steel itself is protected by coats of paint.*

Q Can my home be built to resist earthquake and hurricanes?

A *Positive connections and the strength of steel provide great protection against earth quake and hurricanes. Steel's high strength and ductility make it the best construction material for earthquake resistant design.*

Q Will I be able to remodel my home?

A *Since steel frame allows for larger span, a house can be designed without interior load bearing partitions, making it easier for home owner to complete alterations without affecting the structure.*

Q How do I hang pictures in a steel framed home?

A *As in a traditional home, depending on the weight of the picture, you can hang it from the drywall with toggle bolts or hangers.*

Q Will I have to pay higher insurance premium for my homeowner's insurance?

A *Because of steel's excellent performance record in earthquakes, because it is not affected by termites and is non-combustible, homeowners of steel homes may save on insurance premiums because of the excellent performance record of steel in earthquake and non-combustibility.*

Appendix C: List of Organizations

Acronym **Full Name**	**Country** **Activity**	**Sector Represented / Object**	**Phone** **Fax**	**Web site** **E-Mail**	**Contact** **Address**
ACEC Association of Consulting Engineers of Canada	Canada *Design*	Engineers involved in design services for capital projects (consulting engineers)	Ph: 1 (800) 565 0569 Fax: 1 (613) 236 6193	http://www.acec.ca fstone@acec.ca	Ann Schneider 130, Albert St.. Suite 616 Ottawa ON K1P5G4
AISC American Institute of Steel Construction	USA *Construction*	Structural steel industry	Ph: 1 (312) 670 2400 Fax: 1 (312) 670 5403	http//www.aiscweb.com cattan@aiscmail.com	One East Wacker Drive, Suite 3100 Chicago IL 60601-2001
AISE Association of Iron & Steel Engineers	USA *Production*	Steel Process, Steel Mills and Engineering	Ph: 1 (412) 281 6323	http://www.aise.org	
AISI American Iron and Steel Institute	USA *Production & construction.*	Steel mills, producers and suppliers. Structural sheet steel industry. (Steel studs)	Ph: 1 (202) 452 7100 Fax: 1 (202) 463 6573	http://www.steel.org	1101 17th St. Suite 1300 Washington DC 20036-4700
BSIF Building System Institute	USA *Systems*	Umbrella Organization for other building systems groups	Ph: 1 (216) 241 7333 Fax: 1 (216) 241 0105	http://www.taol.com/bsif cdevor@taol.com	Chris Devor
CBLIA Centre Belgo-Luxembourgeois d'information sur l'Acier	Belgium-Luxembourg *Production*	Steel producers in Belgium and Luxembourg, linked to IISI	Ph: 011 (322) 509 1501		Paul Borchgraeve 47, rue Montoyer Brussels Belgium B-1000
CCPE Canadian Council of Professional Engineers	Canada *Design*	Professional engineers in Canada	Ph: 1 (613) 232 2474 Fax: 1 (613) 230 5759	http://www.ccpe.ca info@ccpe.ca	Suite 401, 116 Albert Street Ottawa ON K1P 5G3
CISC Canadian Institute of Steel Construction	Canada *Construction*	Structural steel, open web steel joist and steel platework fabricating industries	Ph: 1 (416) 491 4552 Fax: 1 (416) 491 6461	http://www.buildingweb.com/cisc/index.html CISC_MIKE_GILMOR@compuserve.com	Michael Gilmor. Peter Timley (BC) Suite 300 201 Consumer Road Willowdale ON M2J 4G8
CSPA Canadian Steel Producers Association	Canada *Production*	Primary steel producers in Canada.	Ph: 1 (613) 238 6049 Fax: 1 (613) 238 1832	http://www.canadiansteel.ca cspacpa@canadiansteel.ca	1425-50 O'Connor Street Ottawa ON K1P 6L2
CSSI Canadian Sheet Steel Building Institute. (CSSI)	Canada *Construction*	Structural sheet steel Industry (Steel studs and steel decks)	Ph: 1 (519) 650 1285 Fax: 1 (519) 650 8081	http://www.cssbi.ca sfox@cssbi.ca	Steve Fox 652 Bishop St. N., Unit 2A Cambridge ON N3H 4V6
CWB Canadian Welding Bureau	Canada	Welding Certification	Ph: 1 (905) 542 1312	http://www.cwbgroup.com/	7250, West Credit Ave

	Construction		Fax: 1 (905) 542 1318	info@cwbgroup.com	Mississauga ON L5N 5N1
IISI International Iron and Steel Institute	World *Production & construction.*	Steel companies, national and regional steel federations and steel research associations in 50 countries	Ph: 011 (322) 702 8900 Fax: 011 (322) 702 8899	http://www.worldsteel.org steel@iisi.be	Mark Trickett, Dany Houssiau 120 Rue Colonel Bourg Brussels B-1140
LGSEA Light Gauge Steel Engineers Association	USA *Construction*	Engineers and design of steel studs building	Ph: 1 (615) 386 7139	http://www.lgsea.com lgsea@aol.com	Larry Williams 2400 Crestmoor road NashVille TN 37215
MBMA Metal Building Manufacturer Association	USA *Systems*	Building system manufacturers and builders in US.	Ph: 1 (216) 241 7333 Fax: 1 (246) 241 0145	http://www.mbma.com/ administrator@mbma.com	Chris
MCA Metal Construction Association	USA *Systems*	Promoting wider use of metal. Organizes metalcon International.		http://www.mca1.org/	11.S Lasalle Street Suite 1400 Chicago IL 60603
MHI Manufactured Housing Institute	USA *Systems*	Manufacturers, component suppliers, retailers of manufactured homes	Ph: 1 (703) 558 0400 Fax: 1 (703) 558 0401	http://www.mfghome.org/ kami@mfghome.org	2101 Wilson Blvd., Suite 610 Arlington VA 22201-3062
MTC Modern Trade Communications	USA *Promotion / Publication*	Publisher for building systems, steel technology, components, steel roofing and siding	Ph: 1 (847) 674 2200 Fax: 1 (847) 674 3676	http://www.moderntrade.com mtci@moderntrade.com	7450, N.Skokie Blvd Skokie IL 60077
NISD National Institute of Steel Detailing	Canada *Design*	Independent steel detailers	Ph: (817) 860 9890 Fax: 1 (817) 860 9891	http://www.nisd.org ddraft@cam.org	P.O. Box 121484 Arlington, TX 76012
RAG Residential Advisory Group	USA *Construction*	Building industry, steel industry. Promotion of the use of steel in residential construction. AISI sub-committee.	Ph: 1 (202) 452 7202	tlewis@steel.org	
RAIC Royal Architectural Institute of Canada	Canada *Design*	Professional architects	Ph: 1 (613) 241 3600 Fax: 1 (613) 241 5750	http://www.raic.org/ info@raic.org	55 Murray Street, Suite 330 Ottawa ON K1N 5M3
Sustainable Steel	USA *Promotion*	Promotion of steel as material in Green Building. Linked to The Steel Alliance and to SRI	Ph: 1 (412) 922 2772 1 (800) 876 7274 Fax: 1 (412) 922 3213	http://www.sustainable-steel.com sri@recycle-steel.org	Gregory L.Crawford 680, Andersen Drive Pittsburgh PA 15220-2700
		Promotion of steel as sustainable	Ph: 1 (202) 955 5777		Mark Stephenson

The Steel Alliance	USA *Promotion*	and strong material. See Sustainable Steel.	Fax: 1 (202) 955 4549		Washington DC
SBA System Builder Association	USA *Systems*	Building system contractors in US.	Ph: 1 (800) 866 NSBA Fax: 1 (937) 698 6153	http://www.systemsbuilders.org/ info@systemsbuilders.org	28 Lowry Drive P.O. Box 117 West Milton, Ohio OH 45383-0117
SBI Swedish Institute of Steel Construction - Stalbyggnadsintitutet	Sweden *Construction*	Swedish steel construction industry	Ph: 011 (468) 661 0243 Fax: 011 (468) 661 03 05	http://www.sbi.se lars@sbi.se	Lars Hamrebjork, Helena Burstrand, Johan Anderson PO Box 27751 Stockholm Sweden S-115
SCI Steel Construction Institute, UK	UK Construction	British steel construction industry.	Ph: 011 (440) 1344 23345 Fax: 011 (440) 1344 22944	http://www.steel.sci-org reception@steel-sci.org	Dr. Keith Eaton Silwood Park Ascot Berkshire SL5 7QN
SDI Steel Deck Institute	USA Construction	Cold-formed steel decking industry.	Ph: 1 (847) 462 1930 Fax: 1 (847) 462 1940	http://www.sdi.org janet@sdi.org bcromi@sdi.org	P.O. Box 9506 Canton Ohio 44711
SMA Steel Manufacturer Association	USA Production	US minimills	Ph: 1 (202) 296 1515 Fax: 1 (202) 296 2506	http://www.steelnet.org danjczek@steelnet.org	Thomas A. Danjczek 1730 Rhode Island Avenue, NW Suite 907, Washington Washington DC 20036-3101
SRI Steel Recycle Institute, Pittsburgh, (SRI) USA.	USA Recycling	Steel recycling.	Ph: 1 800 YES 1 CAN Fax: 1 (412) 922 3213	http://www.recycle-steel.org/ sri@recycle-steel.org	680 Andersen Drive Pittsburgh, PA 15220-2700
SSCI Steel Service Centre Institute	USA / Canada Distribution	Canadian and American steel distributors and warehouse	Ph: 1 (216) 694 3630 Fax: 1 (216) 694 3940	http://www.sscl.org/ info@ssci.org	Key Center, Suite 2400, 127 Public Square Cleveland Ohio 44114-1216

Appendix D: Comparison between the NBC and LSD

The following present a comparison of allowable span obtained from three different sources:

1. Table 9.23.4.A: *"Maximum Spans for Steel beam Supporting Floors in Dwellings Units"* specified by the NBC
2. Maximum Spans calculated for the maximum deflection allowed by the NBC.
3. Maximum resisting moment calculated by the Limit State Design method (LSD.)

According to NBC representatives, the span table was calculated prior to the adoption of the "Limit State Design" and the results differ significantly from what the current Standard would produce.

Design Assumption

The calculations use the same design loads and assumption than the table span 9.23.4.A. provided by the NBC:

(1) Simply supported beam.

(2) Laterally supported top flange.

(3) Yield Strength 300 MPa.

(4) Maximum deflection limit 1/360 of the span.

(5) Live load 1.9 kPa / 1st Floor.

(6) Dead load 1.5 kPa (assuming a wood floor)

The results show that,

- With all the other parameter equals, the NBC table allows slightly longer spans than computed by the maximum deflection criteria.
- The maximum deflection criteria is the limiting factor in all cases.
- The span allowed by the NBC are between 15 to 25% shorter than calculate by the LSD method.

Table D-1 indicates the maximum span obtained from each source:

- The maximum span provided in the NBC are in italic,
- The spans limited by maximum deflection are in Bold and,
- The spans limited by strength according to LSD are in normal fonts

Table D-1: Maximum Spans Comparison Table

	Supported Joist Length		Ft	8	10	12	14	16	18	20
			m	2.4	3	3.6	4.2	4.8	5.4	6
Profiles	Characteristics		Maximum Spans, m.							
W150x22	Mx (kN/m)	47.52	*NBC*	*4.70*	*4.20*	*3.90*	*3.60*	*3.40*	*3.20*	*3.30*
	Ix (m4)	1.21E-5	**Defl.**	**3.95**	**3.67**	**3.46**	**3.29**	**3.15**	**3.03**	**2.93**
			Mom.	5.79	5.18	4.73	4.38	4.09	3.86	3.66
W200x21	Mx (kN/m)	59.94	*NBC*	*5.20*	*4.70*	*4.30*	*4.00*	*3.70*	*3.50*	*3.40*
	Ix (m4)	2.00E-5	**Defl.**	**4.67**	**4.34**	**4.09**	**3.89**	**3.72**	**3.58**	**3.46**
			Mom.	6.50	5.82	5.31	4.92	4.60	4.34	4.11
W200X27	Mx (kN/m)	75.33	*NBC*	*6.30*	*5.70*	*5.20*	*4.80*	*4.50*	*4.30*	*4.10*
	Ix (m4)	2.58E-5	**Defl.**	**5.07**	**4.72**	**4.45**	**4.23**	**4.05**	**3.90**	**3.76**
			Mom.	7.29	6.52	5.95	5.51	5.15	4.86	4.61
W200X31	Mx (kN/m)	90.45	*NBC*	*6.90*	*6.20*	*5.70*	*5.30*	*5.00*	*4.70*	*4.50*
	Ix (m4)	3.14E-5	**Defl.**	**5.41**	**5.03**	**4.74**	**4.51**	**4.32**	**4.16**	**4.01**
			Mom.	7.99	7.14	6.52	6.04	5.65	5.33	5.05
W250X24	Mx (kN/m)	82.89	*NBC*	*6.20*	*5.60*	*5.10*	*4.80*	*4.50*	*4.20*	*4.00*
	Ix (m4)	3.42E-5	**Defl.**	**5.58**	**5.19**	**4.89**	**4.65**	**4.45**	**4.28**	**4.14**
			Mom.	7.65	6.84	6.24	5.78	5.41	5.10	4.84
W250X33	Mx (kN/m)	114.48	*NBC*	*7.90*	*7.10*	*6.50*	*6.00*	*5.70*	*5.40*	*5.10*
	Ix (m4)	4.89E-5	**Defl.**	**6.27**	**5.83**	**5.50**	**5.23**	**5.00**	**4.82**	**4.65**
			Mom.	8.99	8.04	7.34	6.79	6.35	5.99	5.68
W250X39	Mx (kN/m)	138.51	*NBC*	*8.70*	*7.80*	*7.20*	*6.70*	*6.30*	*5.90*	*5.60*
	Ix (m4)	6.01E-5	**Defl.**	**6.70**	**6.23**	**5.88**	**5.59**	**5.35**	**5.15**	**4.98**
			Mom.	9.89	8.84	8.07	7.47	6.99	6.59	6.25
W310X31	Mx (kN/m)	129.60	*NBC*	*8.00*	*7.20*	*6.60*	*6.10*	*5.80*	*5.40*	*5.20*
	Ix (m4)	6.50E-5	**Defl.**	**6.89**	**6.42**	**6.05**	**5.75**	**5.50**	**5.30**	**5.12**
			Mom.	9.56	8.55	7.81	7.23	6.76	6.37	6.05
W310X39	Mx (kN/m)	164.70	*NBC*	*9.50*	*8.60*	*7.90*	*7.30*	*6.90*	*6.50*	6.20
	Ix (m4)	8.51E-5	**Defl.**	**7.52**	**7.00**	**6.60**	**6.28**	**6.01**	**5.79**	*5.59*
			Mom.	10.78	9.64	8.80	8.15	7.62	7.19	*6.82*

Figure D-1 represents the maximum steel beam span calculated according to the three methods, NBC, Maximum deflection and Limit state for the same loads as in NBC (See design assumption) for a total floor length supported of 2.4 m. In all cases, the spans are limited by deflection.

Figure D-1: Beam Selection for a fixed supported joist.

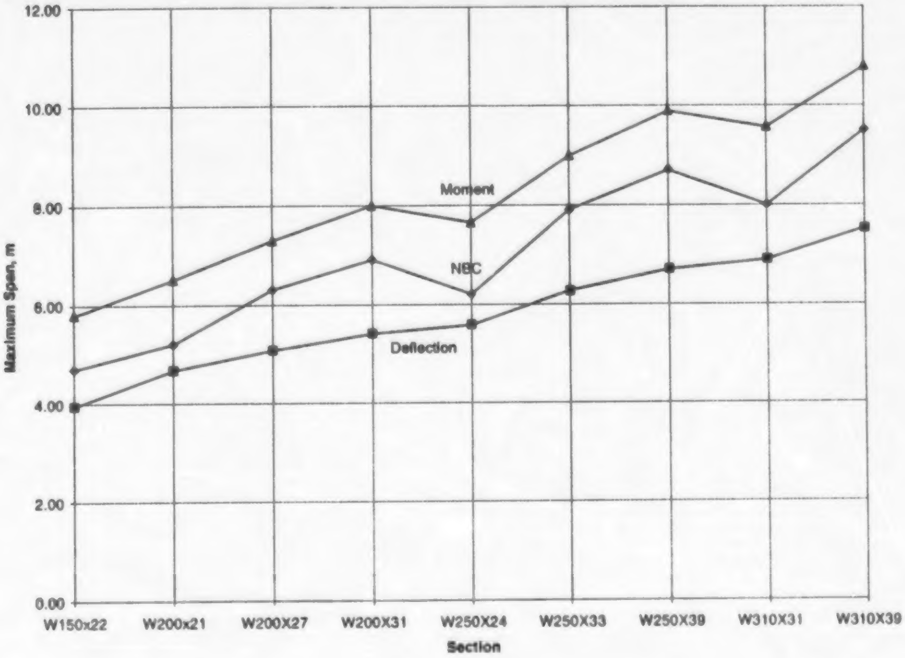
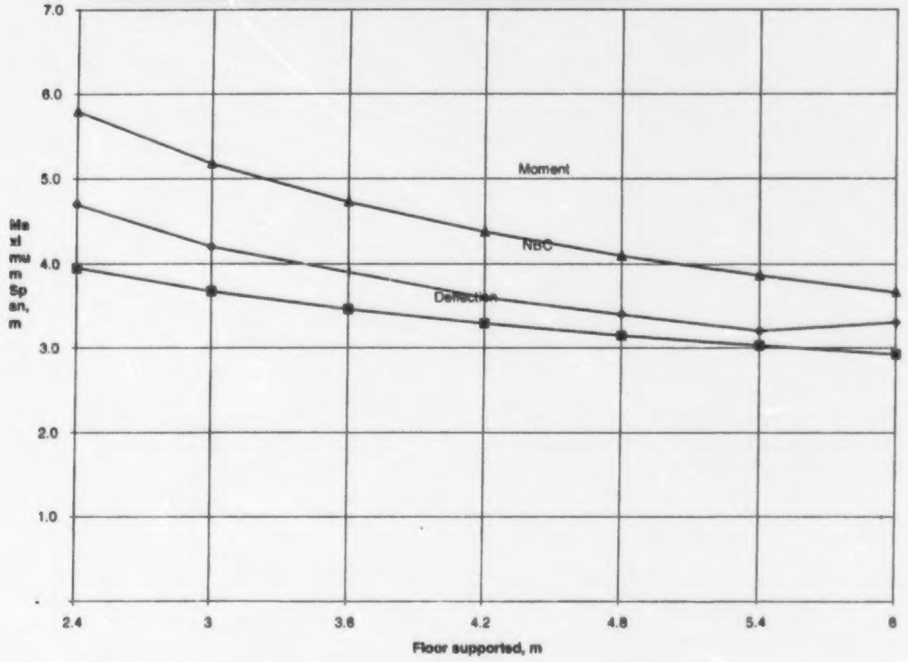


Figure D-2 shows the relationship between the maximum Spans and the supported wood floor length for a W150x22 beam. The spans are also limited by the maximum deflection.

Figure D-2: Maximum Span for a W150x 22 Beam



Appendix E: Snapshot of Canadian Steel in 1997

1. The Canadian Steel Industry in 1997

- Number plants: 17.
- Location: Six provinces (Alberta, Saskatchewan, Manitoba, Ontario, Quebec, Nova Scotia) Ontario accounts for 70% of Canadian capacity
- Work force: 33,600 employees
- Sales: over $11 billion in sales, $3 billion in exports in 1996
- Main customers: supplies the transportation, oil and gas, appliance, packaging, construction industries
- Distribution: 35 percent of volume produced is distributed by a network of steel service centers, which act as wholesalers and processors of steel serves primarily North American markets
- Industry segments: flat-rolled products (e.g. plate and sheet steels), long products (e.g. concrete reinforcing bar and structural steel), specialty and alloy steels (e.g. stainless steel and tool steels, in both long and flat products)

2. Making Canadian steel

- **Blast furnace** operators (often referred to as integrated producers) combine iron ore, limestone and coke in a blast furnace to produce molten iron. The iron is then refined with scrap and other additives in a basic oxygen furnace to produce liquid steel. Such facilities are capital-intensive and are capable of producing two to four million tons of steel annually. Algoma, Dofasco and Stelco operate such facilities in Canada. Dofasco also has an electric furnace. In the United States, integrated producers include USX, Bethlehem, LTV, Inland, and AK Steel. Lake Erie Steel Company Limited, commissioned in 1980, is the newest greenfield integrated facility in North America.
- **Electric furnace** operations (often referred to as minimills) melt scrap or direct reduced iron in electric arc furnaces to produce liquid steel. Less capital-intensive than integrated producers, they are capable of producing 250,000 to over one million tons annually. Originally small-scale plants serving local markets for structural steel products, minimills in North America are now major players and compete with integrated plants in most product areas. In Canada, most steelmaking facilities except for the three noted above are electric furnace operations: Co-Steel Lasco, Gerdau Courtice Steel Inc., Gerdau MRM Steel Inc., Hamilton Specialty Bar Division of Slater Steel Inc., IPSCO Inc., Ivaco Inc., Sammi-Atlas Inc., Sidbec-Dosco (Ispat) Inc., Stelco-McMaster Ltée, and Sydney Steel Corporation. They produce flat products, long products and stainless and speciality steels. Leading minimills in the United States include Nucor, Oregon Steel, North Star Steel and Birmingham Steel.
- QIT-Fer et Titane Inc. uses a third process. It produces iron from ilmenite ore using a proprietary electric furnace process, then uses an oxygen furnace to produce steel.

3. Recent competitive challenges

- New entrants in the U.S. industry; dramatic restructuring of traditional players
- Integration of North American steel market: FTA, NAFTA
- New competitors in Asia, Europe and South America, many subsidized
- Rising environmental awareness and expectations

4. Canadian steel response

- Corporate repositioning: customer focus, cost reduction,
- Restructuring
- New products:
  - over half of automotive sheet steels new since 1989
  - new steel for pipelines, construction
  - niche products for world markets
  - Investment in technology, employee skills
- over $3.8 billion since 1989 to upgrade facilities
- information technology for process and inventory control,
- testing, customer service
- new work methods, management structures
- doubled expenditure in employee training
- Collaborative research: thin strip casting, process modelling,
- electronic sensors

5. Performance

- Productivity up over 50% 1988-94
- Scrap recycling equal to over half of steel output
- Total energy consumption down 25% from early 1980's
- Carbon dioxide emissions down 30% from 1980
- Leaders in North American profits per ton 1994, 1995 and 1996
- Nationally recognized innovator in life-long learning for employees

6. Outlook: preparing to meet tough competition head-on

- North American market growth 1-2%; 4% for stainless
- New American capacity: 15-20 million tons by 1999
- Globalization of major customers (automotive, appliances)
- Continuing pressures from offshore overcapacity
- Rapid and accelerating technological change
- Continuing drive for environmental improvement
- Challenging other materials in traditional markets (autos, bridge construction) and new ones (housing, electrical transmission)

- Over $1.4 billion in investments underway in Canada
- Investments in training to double 1994-1997

Source: Canadian Steel Producers Association

Appendix F: What is steel?

What is steel?

Steel is a metal composed of iron plus varying amounts of carbon as well as other elements such as chromium, nickel, molybdenum, zirconium, vanadium, tungsten, and so on. (How is steel made?)

Different types of steel - that is, steel with different properties and characteristics - are produced by adjusting the chemical composition and adapting any of the different stages of the steelmaking process, such as rolling, finishing and heat treatment. As each of these factors can be modified, there is potentially virtually no limit to the number of different steels that can be made. Currently there are over 3,000 catalogued grades available (chemical compositions) of steel, not counting those created to meet custom demand, ranging from basic grades (such as for railway tracks) to sophisticated high-alloy and stainless grades for specialised applications.

Products

Steel slabs, billets and blooms are known as semi-finished products. Finished products include: hot- or cold-rolled flat products (such as plates, coils or sheets) and hot-rolled long products (such as wire, bars, rails or beams.

Applications

Steel is used in a vast array of products. The largest markets for steel are construction (buildings, transport infrastructure, etc.), automotive and packaging. Electronic components, industrial equipment and medical applications are also important markets, particularly for special steels and stainless steels.

Production

The steel industry world-wide produces over 750 million tons of crude steel each year (based on average annual production in the past decade). The largest steel-producing countries are China, Japan and the United States, which each produce around 100 million tons of this total. Russia, FR Germany and Rep. of Korea each produce around 40-50 million tons.

Stainless steel production has climbed rapidly in the past decade: over 16 million tons of finished stainless steel were produced in 1997, compared to 13 million tons in 1988 -- an increase of more than 23 percent. Production has increased by more than 50 percent in Europe and Asia in that period. The largest stainless steel-producing countries are Japan (nearly 4 million tons), the United States (2 million tons), and Germany, Rep. of Korea, Italy and France, each of which produced over 1 million tons of finished stainless steel in 1997.

Consumption

Steel use in any country is closely linked to its economy, with the largest consumption in the wealthiest countries of the world. Steel consumption of finished steel products ranges from approximately 20 kilograms per person per year in Africa to around 340 kg in Europe, 420 kg in the North America and 635 kg in Japan. However, the largest consumers are in Asia: Singapore (1,200 kg/capita), Taiwan ROC (over 970 kg) and Rep. of Korea (830 kg). Per capita consumption is climbing rapidly in Asia due to investments in industry, transport infrastructure, construction and overall improved standards of living: for example, in the past decade, per capita consumption has risen by nearly 470 percent in Malaysia, 240 percent in the Republic of Korea, and nearly 80 percent in China.

Process routes

It is sometimes argued that it is better to make steel via a particular process route, whether the traditional integrated route (using coal, iron ore and scrap) or the electric arc furnace route, which uses scrap as its basic raw material. In reality, both routes are valid, depending on local circumstances, including such factors as availability of scrap and other raw materials; local energy costs; scrap prices, local workforce skills, and so on. Production also differs according to the types of steel required, from the basic grades for heavy construction uses to the most specialised custom steels.

Recycled steel (scrap) is a required and essential component of new steel, making steel a naturally environmentally responsible material. In basic oxygen steelmaking, scrap represents up to 30 percent of the raw materials charged into the furnace. It represents between 90 and 100 percent of the charge in EAF (electric arc furnace) production, which is also the principal route for stainless steel production.

Steel is 100 percent recyclable: moreover, it can be used over and over again with no downgrading to a lower quality product. Steel's magnetic properties make it simple to extract from other materials for recycling. Approximately 350 million tons of steel scrap are recycled each year. Stainless steel is a very valuable commodity and is therefore almost entirely recycled.

Environmental improvements

There is no one factor to explain the many environmental improvements achieved by the steel industry in recent years. One trend has become clear however: the steel industry has shifted its focus from end-of-pipe collection of emissions to considering improvements at every single stage of the steelmaking process. Steelmakers have therefore achieved even further emissions reductions by investing in overall cleaner production, better maintenance and improved practices. New technologies, operating practices, employee education and management attention have all been important. Many of the improvements have resulted from very heavy investment programmes. It is estimated that at least 10 percent of all steel industry capital expenditures have been specifically on environment improvement -- or more than US$ 20 billion in the last ten years alone. This is almost certainly an underestimate, since it does not include investment in new steelmaking processes - such as continuous casting, thin slab casting or coal injection - which enable much cleaner technology to be introduced.

Employment

Steel production in the world has risen by approximately 30 percent in the past 25 years. In the same period, estimated employment in the major steel-producing countries (excluding China) has fallen from around 2.5 million to 1.3 million people. This enormous reduction has been the result of major investments by the world's steelmakers in modern steelmaking processes and technologies. The new technologies not only improve productivity but also increase yield efficiency while reducing resource consumption and the environmental impact of the steelmaking process.

A modern material in a competitive market

While the manufacturing materials available to man changed little for hundreds of years, the latter half of the 20th century has seen a tremendous influx of new and exciting materials. The world of steel is no exception. Steel is not a single material, but a vast range of different materials constantly evolving as steel applications evolve. For example, more than 80 percent of the steels used in automobile production today did not exist ten years ago. In automotive as in other applications, steelmakers are continually working in collaboration with their customers, improving and modifying their products, and creating innovative new steels.

Common uses of steel:

They are examples of steel uses everywhere: in road, rail and bridge structures, food and beverage cans, cars, construction elements such as reinforced concrete walls and pillars, bicyles, airplanes, and in a vast array of other products. Steel is used in furnishings (desks, filing cabinets, handles, hinges, locks and keys, light fittings, curtain rails, chair and table legs, etc.), office items (computers, paperclips, staples, diskettes...), or in motors, mobile phones, industrial machinery, flagpoles, lawnmowers

Stainless steel

Many of the items used every day are made of stainless steel, which is both hard wearing and beautiful. It's used in personal accessories (glasses frames, watches, buttons, clasps, zippers, key rings...) and household items (cutlery, sinks, saucepans and utensils, appliances), and it is prized by interior designers for use in modern furniture, lights and decorative elements. Stainless steel is also invaluable in highly specialized applications: its highly resistant and easy to clean surface makes stainless steel extremely hygienic. It is therefore used extensively in hospital and sterile environments, food processing plants, restaurants, and many other uses.

Glossary

Alloy steels

Alloy steels have enhanced properties due to the presence of 1 or more special elements, or to the presence of larger proportion of elements such as manganese and silicon than are present in carbon steels.

Apparent consumption

Total shipments minus exports plus imports of steel.

Bar

A finished steel product, commonly in flat, square, round or hexagonal shapes. Rolled from billets, bars are produced in two major types, merchant and special.

Basic oxygen steelmaking

The process whereby hot metal and steel scrap are charged into a basic oxygen furnace (BOF). High purity oxygen is then blown into the metal bath, combining with carbon and other elements to reduce the impurities in the molten charge and convert it into steel.

Billet

A piece of semi-finished iron or steel that is nearly square and is longer than a bloom. Bars and rod are made from billets.

Blast furnace

A large cylindrical structure into which iron ore is combined with coke and limestone to produce molten iron.

Bloom

A semi-finished product, large and mostly square in cross-section. Blooms are shaped into girders, beams, and other structural shapes.

Carbon steels

The largest percentage of steel production. Common grades have a carbon content ranging from 0.06% to 1.0%.

Coal

The primary fuel of integrated iron and steel producers.

Coke

A form of carbonized coal burned in blast furnaces to reduce iron ore pellets or other iron-bearing materials to molten iron.

Coke ovens

Ovens where coke is produced. Coal is usually dropped into the ovens through openings in the roof, and heated by gas burning in flues in the walls between ovens within the coke oven battery. After heating about 18 hours, the end doors are removed and a ram pushes the coke into a quenching car for cooling before delivery to the blast furnace.

Coil

A finished steel product such as sheet or strip which has been wound or coiled after rolling.

Cold rolling

The passing of sheet or strip that has previously been hot rolled and pickled through cold rolls, i.e. below the softening temperature of the metal. Cold Rolling makes a product that is thinner, smoother, and stronger than can be made by hot rolling alone.

Continuous casting

A process for solidifying steel in the form of a continuous strand rather than individual ingots. Molten steel is poured into open-bottomed, water-cooled molds. As the molten steel passes through the mold, the outer shell solidifies.

Crude steel

Crude steel: crude steel is steel as it comes out of the initial steelmaking process or continuous caster, but before it has been rolled, formed or heat treated to make products such as slabs or wires. It is the steel in the first solid state after melting, suitable for further processing or for sale. Synonymous to *raw steel.*

Direct reduction

A family of processes for making iron from ore without exceeding the melting temperature. No blast furnace is needed.

Electrical steels

Specially manufactured cold rolled sheet and strip containing silicon, processed to develop definite magnetic characteristics for use by the electrical industry.

Electric arc furnace

An electric furnace used to melt steel scrap or direct reducted iron.

Flat products

A term referring to a class of products including sheet, strip, and plate that are made from slabs.

Galvanized steel

The product produced when hot or cold rolled sheet or strip is coated with zinc either by the hot-dipping or electrolytic deposition process. Zinc coating applied by the hot dip method is normally heavy enough to resist corrosion without additional protective coating. Materials electrolytically galvanized are not used for corrosion resistant applications without subsequent chemical treatment and painting except in mild corrosive conditions, due to the thin coating of zinc. Galvanize is a pure zinc coating. A special heat-treating process converts the pure zinc coating to a zinc/iron alloy coating, and the product is known as Galvanneal.

Hot metal

Molten iron produced in the blast furnace.

Hot rolling

Rolling semi-finished steel after it has been re-heated.

Integrated steelmaker

A producer that converts iron ore into semi-finished or finished steel products. Traditionally, this required coke ovens, blast furnaces, steelmaking furnaces, and rolling mills. A growing number of integrated mills use the direct reduction process to produce sponge iron without coke ovens and blast furnaces.

Iron ore

The primary raw material in the manufacture of steel.

Ladle metallurgy

The process whereby conditions (temperature, pressure and chemistry) are controlled within the ladle of the steelmaking furnace to improve productivity in preceding and subsequent steps and the quality of the final product.

Limestone

Used by the steel industry to remove impurities from the iron made in blast furnaces. Magnesium-containing limestone, called *dolomite*, is also sometimes used in the purifying process.

Line pipe

Used for transportation of gas, oil or water generally in a pipeline or utility distribution system.

Mechanical tubing

Welded or seamless tubing produced in a large number of shapes to closer tolerances than other pipe.

Minimill

A small non-integrated or semi-integrated steel plant, generally based on electric arc furnace steelmaking. Minimills produce rods, bars, small structural shapes and flat rolled products.

Net ton

See ton

Oil country tubular goods (OCTG)

Pipe used in wells in oil and gas industries, consisting of casing, tubing, and drill pipe. Casing is the structural retainer for the walls; tubing is used within casing oil wells to convey oil to ground level; drill pipe is used to transmit power to a rotary drilling tool below ground level.

Open-hearth process

A process for making steel from molten iron and scrap. The open-hearth process has been replaced by the basic oxygen process in most modern facilities.

Pellets

An enriched form of iron ore shaped into small balls.

Pig iron

High carbon iron made by the reduction of iron ore in the blast furnace.

Plate

A flat rolled product rolled from slabs or ingots, of greater thickness than sheet or strip.

Rolling mill

Equipment that reduces and transforms the shape of semi-finished or intermediate steel products by passing the material through a gap between rolls that is smaller than the entering materials.

Semi-finished products

Before it can be used in consumer products such as cars, cans, bridges, and so on, crude steel is formed into the semi-finished or finished products which will be delivered to the carmaker, canmaker or bridgemaker. Semi-finished products are slabs, billets and blooms: huge basic steel shapes that will subsequently be processed to create finished products: such as sheet steel for auto body parts and appliances, wires to make reinforced concrete, and other usable steel shapes.

Sheet

A flat rolled product over 12 inches in width and of less thickness than plate.

Sheet piling

Rolled sections with interlocking joints (continuous throughout the entire length of the piece) on each edge to permit being driven edge-to-edge to form continuous walls for retaining earth or water.

Sintering

A process which combines ores too fine for efficient blast furnace use with flux stone. The mixture is heated to form clumps, which allow better draft in the blast furnace.

Slab

A wide semi-finished product made from an ingot or by continuous casting. Flat rolled steel products are made from slabs.

Sponge iron

The product of the direct reduction process. Also known as *direct reduced iron (DRI)*.

Stainless steels

Stainless steels offer a superior corrosion resistance due to the addition of chromium and/or nickel to the molten steel.

Standard Industrial Classification (SIC)

The Standard Industrial Classification (SIC) is a coding system that defines industries in terms of specific groupings of activities. Every industry is assigned a code, and there are two-, three-, and four-digit codes. Two-digit codes represent the broadest industry definition and the broadest range of activities, four-digit codes the most detailed industry definition and the most detailed range of activities. For example, SIC 29 represents the Primary Metal Industries (which include both primary and semi-fabricated metals), SIC 2919 Other Primary Steel Industries. If at least 50% of an establishment's value added derives from activities associated with a particular SIC code, the establishment is classified in that industry.

Standard pipe

Used for low-pressure conveyance of air, steam, gas, water, oil or other fluids and for mechanical applications. Used primarily in machinery, buildings, sprinkler systems, irrigation systems, and water wells rather than in pipelines or distribution systems.

Strip

A flat rolled product customarily narrower in width than sheet, and often produced to more closely controlled thickness.

Structural shapes

Rolled flange sections, sections welded form plates, and special sections with at least one dimension of their cross-section 3 inches or greater. Included are angles, beams, channels, tees and zees.

Structural pipe and tubing

Welded or seamless pipe and tubing generally used for structural or load-bearing purposes aboveground by the construction industry, as well as for structural members in ships, trucks, and farm equipment.

Tin coated steel

Cold rolled sheet, strip, or plate coated with tin or chromium.

Ton

a) A unit of weight in the U.S. Customary System, an avoirdupois unit equal to 2,240 pounds. Also known as *long ton*. b) A unit of weight in the U.S. Customary System, an avoirdupois unit equal to 2,000 pounds. Also known as *short ton*. Also known as *net ton*.

Tonne

A metric ton, equivalent to 1,000 kilograms.

Wire: drawn and/or rolled

The broad range of products produced by cold reducing hot rolled steel through a die, series of dies, or through rolls to improve surface finish, dimensional accuracy, and physical properties.

This glossary is taken from the Canadian Steel Producers Association's 1994 information binder and from the Environment Canada report, *Emissions from the Canadian Iron and Steel Industry in 1992*.

Appendix G: Metal Building System Builders in Canada

Company Name	Location	Province	Size Code
Alta-Fab Structures Ltd.	Edmonton	Alta	5
Brytex Building Systems Inc.	Edmonton	Alta	5
Scott Steel Ltd.	Edmonton	Alta	5
Makloc Building Inc.	Leduc	Alta	5
Three Star Steel (Calgary) Ltd.	Calgary	Alta	4
Triangle Steel (Calgary) Limited	Calgary	Alta	4
Twister Pipe Ltd.	Calgary	Alta	4
Waiward Steel Fabricators Ltd.	Edmonton	Alta	3
M 3 Steel (Kamloops) Ltd.	Kamloops	BC	4
West-Man Culvert & Metal Co Ltd.	Brandon	Man	6
Dominion Bridge Inc.	Amherst	NS	5
Glen White Industriesltd.	Aylmer	On	5
Noront Steel (1981) Ltd.	Sudbury	On	5
Future Steel Holdings Ltd.	Brampton	On	4
Strato-Steel Limited	Caledon	On	4
Growers Greenhouse Supplies Inc.	Lincoln	On	4
M & G Steel Ltd.	Mississauga	On	3
Pioneer Steel Manufacturing Limited	Mississauga	On	3
Paul Boers Greenhouse Construction Ltd.	Niagara-On-The-Lake	On	3
Les Constructions Beauce Atlas Inc.	Sainte Marie	Qc	6
Gsm Production Inc.	Montreal	Qc	5
Honco Inc.	Bemiere	Qc	4
Tecno Metal Inc.	Quebec	Qc	4
Mecart Inc.	Sainte-Foy	Qc	4
Les Industries Super Metal Inc.	Vanier	Qc	4
Corporation D'Acier Ungava Usc Ltee.	Saint-Hubert	Qc	3
Laflamme Air Libre Inc.	Saint-Hippolyte	Qc	3
Les Aciers Solider (1985) Inc.	Chester-Est	Qc	2
Les Batiments J D L Inc.	Saint-Germain-De-Granthan	Qc	1
Prairie Steel Products Ltd.	Blucher No. 343	Sask	4
Master Manufacturing Inc.	Moose Jaw	Sask	3

Appendix H: Canadian Fabricators

Table H-1: List of Main Fabricators in Canada

Company	City / Municipality	Prov.	Size	S	P	J	*	C
Acropolis Steel Industries (1983) Ltd.	Calgary	Alta	4					
Atlas Steel Industries Inc.	Calgary	Alta	4	X				X
C.W. Carry (1967) Ltd.	Edmonton	Alta	n/a	X	X			X
Canadian Erectors Limited	Calgary	Alta	n/a	X	X		X	X
Canam Steel Works	Calgary	Alta	n/a			X		X
Canron Inc.	Calgary	Alta	5					
Central Fabricators (1994) Ltd.	Edmonton	Alta	5	X	X			X
Collins Industries Ltd.	Edmonton	Alta	5	X				X
Dominion Bridge, Inc.	Calgary	Alta	n/a	X	X		X	X
Empire Iron Works Ltd.	Edmonton	Alta	5	X	X			X
Eskimo Steel Limited	Edmonton	Alta	4	X				X
Geco Steel Corporation Ltd.	Calgary	Alta	4					
Moll Industries Ltd.	Calgary	Alta	4	X				X
Northern Weldarc Ltd.	Edmonton	Alta	3					
Omega Joists Inc.	Nisku	Alta	4			X		X
Precision Steel & Manufacturing Ltd.	Edmonton	Alta	n/a	X				X
Quality Fabricating & Supply Ltd.	Edmonton	Alta	4					
Rampart Steel Ltd.	Edmonton	Alta	3	X				X
Renbec Industries Ltd.	Calgary	Alta	4					
Scott Steel Ltd.	Edmonton	Alta	n/a	X	X			X
Supreme Steel Ltd.	Edmonton	Alta	5	X	X			X
Sureway Metal Systems Ltd.	Calgary	Alta	4					
Triangle Steel (Calgary) Ltd.	Calgary	Alta	n/a	X	X			X
TSE Steel Ltd.	Calgary	Alta	n/a	X	X			X
W.F. Welding & Overhead Cranes Ltd.	Nisku	Alta	n/a	X				X
Walward Steel Fabricators Ltd.	Edmonton	Alta	n/a	X	X			X
Wemas International Ltd.	Calgary	Alta	4					
Western Steel Fabricators Alberta Ltd.	Edmonton	Alta	3					
A I Industries.	Surrey	B.C.	4					
Brenco Industries Ltd.	Delta	B.C.	4					
Canam Steel Works	Surrey	B.C.	n/a			X	X	X
Canron Inc.	Burnaby	B.C.	6					
Canron Inc.	Delta	B.C.	3					
Clearbrook Iron Works Ltd.	Abbotsford	B.C.	3	X				X
Coast Steel Fabricators Ltd.	Port Coquitlam	B.C.	6	X	X			X
Continental Steel Ltd.	Coquitlam	B.C.	4	X		X		X
CRS Construction Ltd.	Mission	B.C.	n/a	X				X
Daam Galvanizing Ltd.	Vancouver	B.C.	4					
Dan-Can Manufacturing Co Ltd.	Burnaby	B.C.	4					
Empire Iron Works Ltd.	Delta	B.C.	5	X				X
George Third & Son	Burnaby	B.C.	n/a	X	X			X
Haney Iron Works Ltd.	Maple Ridge	B.C.	4					
Kay-Son Steel Fabricators A Erectors Ltd.	Coquitlam	B.C.	4					
Kelowna Steel Fabricators Ltd.	Kelowna	B.C.	4					
LLB Modular Bridge Systems Ltd.	Delta	B.C.	n/a	X				X
M3 Steel (Kamloops) Ltd.	Kamloops	B.C.	n/a	X	X			X
Mainland Machinery Ltd.	Abbotsford	B.C.	4					
Maloney Steel Ltd.	Kelowna	B.C.	4					
Marsh Steel Ltd.	Delta	B.C.	4					
M-Tec Steel Industries Ltd.	Delta	B.C.	n/a	X				X
Nova Pole International Inc.	Vancouver	B.C.	4					
Omega Joists Inc.	Surrey	B.C.	n/a			X		X
Rapid-Span Structures Ltd.	Armstrong	B.C.	4	X				X
Solid Rock Steel Fabricating Co. Ltd.	Surrey	B.C.	4	X				X
Steeler Construction Supply Limited	New Westminster	B.C.	3					

Warnaar Steel-Tech Ltd.	Kelowna	B.C.	n/a	X				X
World Fabricators Ltd.	Surrey	B.C.	3					
X.L. Ironworks Co.	Surrey	B.C.	n/a	X		X		X
Canron Inc. - Fabrication West	New Westminster	B.C.	n/a	X	X			X
Abesco Ltd.	Winnipeg	Man	5	X				X
Canam Steel Works	Winnipeg	Man	n/a			X	X	X
Dominion Bridge Inc.	Winnipeg	Man	7					
Empire Iron Works Ltd.	Winnipeg	Man	5					
Omega Joists Inc.	Winnipeg	Man	n/a			X	X	X
Shopost Iron Works (1989) Ltd.	Winnipeg	Man	n/a	X				X
Dominion Bridge, Inc.	Winnipeg	Man	n/a	X	X			X
Empire Iron Works Ltd.	Winnipeg	Man	n/a	X				X
Canam Steel Works	Moncton	N.B.	n/a	X		X		X
Guy's Welding Ltd.	Saint-Antoine	N.B.	n/a	X				X
Mandate Erectors & Welding Ltd.	Bathurst	N.B.	n/a	X	X			X
Ocean Steel & Construction Ltd.	Saint John	N.B.	6	X	X			X
York Steel Inc.	Fredericton	N.B.	4	X	X			X
G Pelley Limited	Springdale	Nfld	3					
Metal World Inc.	St. John'S	Nfld	4					
Cherubini Metal Works Limited	Dartmouth	N.S.	5	X	X			X
Dominion Bridge, Inc.	Amherst	N.S.	n/a	X				X
Marid Industries Limited	Windsor Junction	N.S.	n/a	X				X
Maritime Steel & Foundries Limited	Dartmouth	N.S.	4					
Maritime Steel & Foundries Limited	New Glasgow	N.S.	6	X	X			X
RKO Steel Limited	Dartmouth	N.S.	5	X	X			X
S & P Welding & Iron Works	North Bay	Ont	5					
A J Braun Mfg Ltd.	Kitchener	Ont	4					
Advanced Tower Limited	Woolwich	Ont	2					
Baycar Steel Fabricating Ltd.	Sudbury	Ont	4					
Bell-Camp Manufacturing Ltd.	Ingersoll	Ont	4					
Benson Steel Limited	Bolton	Ont	n/a	X		X		X
Betco Products.	Brantford	Ont	4					
Bradshaw Iron Workds Ltd.	St. Catherines	Ont	3					
Brampton Plate & Structural Steel Rolling Inc.	Brampton	Ont	4					
Canadian Erectors Limited	St. Catherines	Ont	2					
Canron Inc.	Etobicoke	Ont	6					
Central Ontario Metal & Const Ltd.	Waterloo	Ont	4					
Central Steel Fabricators Limited	Hamilton	Ont	n/a	X				X
Central Welding & Iron Works	North Bay	Ont	n/a	X	X			X
Coastal Steel Construction Limited	Thunder Bay	Ont	4	X	X			X
Cooksville Steel Limited	Mississauga	Ont	4	X		X		X
Cooksville Steel Limited	Kitchener	Ont	3					
Dominion Bridge, Inc.	Oakville	Ont	n/a	X	X	X	X	X
Douglas Steel Company Ltd.	Whitby	Ont	4					
Etobicoke Ironworks Ltd.	York	Ont	5					
Fisco Steel Limited	Vaughan	Ont	4					
G & P Welding & Iron Works	North Bay	Ont	n/a	X	X			X
Gorf Contracting Limited	Schumacher	Ont	n/a	X	X			X
Greco Bros Manlifacturing Co Ltd.	Stoney Creek	Ont	2					
Ground Control Sudbury Ltd.	Sudbury	Ont	4					
H H Robertson Inc.	Hamilton	Ont	5					
Hodgson Steel Inc.	Niagara Falls	Ont	4					
K E W Steel Fabricators Ltd.	Lincoln	Ont	5					
Lameton Metal Works Ltd.	Sarnia-Clearwater	Ont	4					
Le Groupe Canam Manac Inc.	Mississauga	Ont	5					
Ledore Investments Limited	Sarnia-Clearwater	Ont	3					
Linesteel Inc.	Brampton	Ont	2					
Locweld Inc.	Cornwall	Ont	2					
Lorvin Steel Ltd.	Brampton	Ont	n/a	X				X
M & G Steel Ltd.	Mississauga	Ont	n/a	X				X
Mansteel Limited	Erin	Ont	4					
Marcon Custom Metals Inc.	Kitchener	Ont	5					
Mariani Metal Fabricators Limited	Etobicoke	Ont	4					
MBS Steel Ltd.	Brampton	Ont	n/a			X		X

McCabe Steel	Stoney Creek	Ont	4	X	X			X
Mccrindle Steel Industries Ltd.	Windsor	Ont	4					
Mes Steel Ltd.	Brampton	Ont	4					
Metal Shapes Manf Inc.	Woodstock	Ont	3					
Mométal Inc.	Vaughan	Ont	n/a	X	X	X	X	X
Niagara Structural Steel	St. Catharines	Ont	n/a	X	X			X
Nickel City Steel Ltd.	Sudbury	Ont	5					
Norak Steel Construction Limited	Concord	Ont	4	X		X		X
Noront Steel (1981) Limited	Copper Cliff	Ont	n/a	X	X			X
Presland Iron & Steel Ltd.	Kingston	Ont	3					
Prime Steel Inc.	Newcastle	Ont	3					
Samuel Manu-Tech Inc.	Mississauga	Ont	5					
Sass Manufacturing Cc Ltd.	Chatham	Ont	5					0
Shannon Steel Inc.	Orangeville	Ont	3	X				X
Skyhawk Steel Construction Limited	Brampton	Ont	3	X				X
Spec-Fab Inc.	Mississauga	Ont	4					
Spencer Steel Limited	London	Ont	6	X				X
Strato Steel Limited	Bolton	Ont	n/a	X		X	X	X
Supermétal Structures Inc.	Mississauga	Ont	n/a	X	X		X	X
Trenton Machine Tool Inc.	Trenton	Ont	6					
Tresman Steel Industries Ltd.	Mississauga	Ont	4	X		X		X
Tri - Service Metal Products Inc.	Markham	Ont	4					
Walters Inc.	Hamilton	Ont	5	X				X
Canam Steel Works	Mississauga	Ont	n/a			X		X
Canron Inc. - Fabrication East	Rexdale	Ont	n/a	X	X			X
Prebilt Structures Ltd.	Charlottetown	PEI	n/a	X	X			X
Les Constructions Beauce-Atlas Inc.	Ste-Marie de Beauce	Qué.	n/a	X				X
Acier Alouette Ltee.	Laval	Que	3					
Acier J N H Inc.	Mascouche	Que	3					
Acier Métaux Spec Inc.	Chateauguay	Que	n/a	X				X
Acter Fasco (1984) Inc.	Boucherville	Que	1					
Au Dragon Forgé Inc.	Terrebonne	Que	n/a	X				X
Canadian Erectors Limitée	Boisbriand	Que	n/a		X			X
Canam Steel Works	Beauce	Que	n/a	X		X		X
Cartier Structural Steel Ltee.	Montreal	Que	4					
Compagnie De Metal Charland (1987) Ltee.	Laval	Que	4					
Constructions Fermont Inc.	Grand-Mere	Que	4					
Constructions PROCO Inc.	St. Nazaire	Que	n/a	X				X
Dominion Bridge, Inc.	Lachine	Que	7	X	X			X
Fabrimet Inc.	Drummondville	Que	5					
Goodco Ltee.	Laval	Que	4					
Industries Canatal Inc.	Thetford Mines	Que	4	X			X	X
Jean-Yves Fortin Soudure Inc.	Montmagny	Que	n/a	X				X
Lar Machinerie 1983 Inc.	Metabetchouan	Que	6					
Le Groupe Canam Manac Inc.	Saint-Germain	Que	8					
Les Charpentes Métalliques Economiques	Montréal	Que	n/a	X				X
Les Industries Beroma Inc.	Val-D'Or	Que	4					
Les Industries Foresteel Inc.	Montreal	Que	5					
Les Industries V.M. Inc.	Longueuil	Que	3	X				X
Les Metaux Feral Metals Inc.	Bellefeuille	Que	4					
Les Structures C.D.L. Inc.	St-Romuald	Que	n/a	X				X
Locweld Inc.	Candiac	Que	6					
Marshall Steel Limited	Laval	Que	6					
Metaux G B L Inc.	Dolseau	Que	3					
Mometal Inc.	Longueiul	Que	6					
Nico Métal Inc.	Nicolet	Que	4	X				X
Parketal (1985) Inc.	Quebec	Que	4					
Poutrelles Delta Inc.	Ste-Marie de Beauce	Que	n/a			X		X
Produits En Fils Metalliques & Metaux Vite.	Montreal	Que	4					
Quali Métal Inc.	Charlesbourg Ouest	Que	6	X				X
Quéro Métal Inc.	St. Romuald	Que	n/a	X				X
Quirion Métal Inc.	Beauce	Que	4	X				X
Robichaud Metal Inc.	St-Augustin-de-D.	Que	4					
Structal 1982 Inc.	Québec	Que	4	X				X

Structure C 0 S Inc.	Trois-Rivieres	Que	2					
Structure C D L Inc.	Saint-Romuald	Que	4					
Structure d'Acier B.R.L. 2000 Inc.	Drummondville	Que	n/a	X				X
Structure d'Acier Cartier Ltée	St-Laurent	Que	n/a	X				X
Supermétal Structures Inc.	St. Romuald	Que	n/a	X	X			X
Systemes Foretruss Inc.	Gatineau	Que	2					
Technosoude Inc.	Jonquiere	Que	4					
Les Structures Breton Inc.	St-Bruno	Que	n/a	X				X
Les Structures G.B. Ltée	Rimouski	Que	4	X	X			X
Mométal Inc.	Longueuil	Que	n/a	X	X	X		X
Anlin Welding & Steel Fabrication Ltd.	Regina	Sask	3					
Bay Trail Steel Ltd.	Humboldt	Sask	5					
Dominion Bridge, Inc.	Regina	Sask	4	X				X
Elance Steel Fabricating Co Ltd.	Saskatoon	Sask	1					
Industrial Welding (1990) Co Ltd.	Saskatoon	Sask	3					
Supreme Steel Ltd.	Saskatoon	Sask	4	X	X			X
Trylon Manufacturing Company Limited	Woolwich	Sask	4					
Victoria Steel Corporation	Sandwich South	Sask	4					

Table H-2: Company Size Code

Code	Nb Employees
01	0 - 4
02	5 - 9
03	10 - 19
04	20 - 49
05	50 – 99
06	100 - 199
07	200 - 499
08	500 – 599
09	1000 – 1499
10	1500 – 2499
11	2500 - 4999
12	>= 5000

Table H-3: Product / Activity Code

S	Structural
P	Platework
J	Open Web Steel Joist
*	Sales Office
C	CISC's Member

Table H-4: Distribution of Steel Fabricators by Province and Size

	Size										
Province	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**n/a**	**Total**	**% (1)**
Alta			3	10	5				10	28	14%
B.C.			4	14	1	2			10	30	15%
Man					2		1		5	8	4%
N.B.				1		1			3	5	2%
N.S.				1	2	1			2	6	3%
Nfld			1	1						2	1%
Ont		5	8	22	10	3			16	64	32%
PEI									1	1	0%
Que	1	2	4	16	2	5	1	1	17	49	24%
Sask	1		2	4	1					8	4%
Total	2	7	22	69	23	12	2	1	64	202	
% (2)	1%	5%	16%	50%	17%	9%	1%	1%			

(1) Percent of Total
(2) Percent of known Sizes

Table H-5: Distribution by Products and Size

	Size										
Product	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**n/a**	**Total**	**% (3)**
J				1					8	9	9%
P									1	1	1%
S			5	9	4	2			26	46	45%
S,J				4					5	9	9%
S,J,P									3	3	3%
S,P				5	5	3	1		21	35	34%
n/a	2	7	17	50	14	7	1	1		99	
Total	2	7	22	69	23	12	2	1	64	202	
Percent (1)	1%	5%	16%	50%	17%	9%	1%	1%			

(3) Percent of known activities
(4) Percent of known sizes

Appendix I: Structural Analysis

Table I-1: Members extreme results

	Force kN						Moment kN-m			
	Fx		Fy		Fz		My		Mz	
Member	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
B1	21.72	-10.5	53.48	-53.82	0.01	-1.03	1.03	-1.02	38.15	-49.1
B2	40.09	-30.68	139.9	-127.91	0	-5.57	5.85	-5.85	74.62	-100.16
B3	24.03	-12.67	68.73	-53.37	0.01	-0.85	1.02	-1.03	38.18	-62.74
B11	15.91	-18.62	49.23	-86.59	0.04	-2.64	2.41	-0.76	36.42	-79.01
B12	15.9	-30.67	94.81	-93.14	0	-4.13	4.33	-4.33	72	-86.52
B13	11.66	-19.55	56.96	-49.23	0.02	-0.66	0.76	-0.76	36.42	-51.97
C1	37.93	-30.91	0.01	-0.01	0.21	-0.03	0.29	-0.36	0.03	-0.04
C2	71.75	-33.83	0.01	-0.01	0.29	0.01	0.45	-0.61	0.04	0
C3	28.22	-47.31	0.03	-0.03	-0.14	-0.94	2.88	-2.82	0.09	0
C4	34.23	-35.43	0.01	-0.01	0.89	-0.63	1.35	-1.41	0.03	-0.04
C5	72.56	-34.22	0.01	-0.01	-0.02	-0.34	0.66	-0.52	0.04	0
C6	47	-23.29	0.03	-0.03	0.04	-0.01	0.33	-0.26	0.09	0
J1	0.38	-0.42	32.5	-32.5	0.02	-2.5	1.2	-1.18	15.82	-28.08
J2	0.78	0.05	32.4	-32.4	0	-0.13	1.45	-1.45	16.02	-27.6
J3	0.62	-0.46	32.5	-32.5	0.02	-1.76	1.19	-1.2	15.82	-28.08
J11	1.51	-0.41	29.85	-29.85	0	-1.82	0.9	-0.87	14.54	-25.78
J12	6.1	-4.69	29.74	-29.74	0	-2.2	1.08	-1.08	14.76	-25.26
J13	1.57	-0.5	29.85	-29.85	0	-1.29	0.89	-0.88	14.54	-25.78
S1	16.81	-12.74	34.99	-23.2	0.01	-1.54	0.67	-0.74	23.65	-27.16
S2	9.57	-10.05	28.32	-15.65	0.01	-1.37	0.66	-0.64	13.53	-16.56
S11	15.8	-9.21	28.09	-19.65	0.01	-0.72	0.49	-0.47	21.05	-22.67
S12	8.59	-13.68	31.73	-16.39	0.01	-1.01	0.48	-0.48	16.85	-17.93
X1	-45.53	-112.38	0.07	-0.07	0	0	0	0	0.06	0
X2	-76.16	-239.67	0.09	-0.09	0	0	0	0	0.07	0
X3	-18.62	-108.02	0.07	-0.07	0	0	0	0	0.06	0
X4	-51.88	-108.01	0.07	-0.07	0	0	0	0	0.06	0
X5	-113.57	-246.58	0.09	-0.09	0	0	0	0	0.07	0
X6	-68.86	-127.99	0.07	-0.07	0	0	0	0	0.06	0
X11	-30.37	-102.43	0.07	-0.07	0	0	0	0	0.06	0
X12	-48.44	-185.85	0.07	-0.07	0	0	0	0	0.06	0
X13	-17.6	-98.45	0.07	-0.07	0	0	0	0	0.06	0
X14	-44.13	-98.42	0.07	-0.07	0	0	0	0	0.06	0
X15	-92.68	-186.62	0.07	-0.07	0	0	0	0	0.06	0
X16	-51.76	-108.84	0.07	-0.07	0	0	0	0	0.06	0
Y1	42.07	-9.75	0.06	-0.06	0	0	0	0	0.05	0
Y2	-2.89	-61.17	0.06	-0.06	0	0	0	0	0.05	0
Y3	32.87	-17.66	0.06	-0.06	0	0	0	0	0.05	0
Y4	8.24	-35.81	0.06	-0.06	0	0	0	0	0.05	0
Y11	37.2	-8.72	0.06	-0.06	0	0	0	0	0.05	0
Y12	-0.52	-50.26	0.06	-0.06	0	0	0	0	0.05	0
Y13	39.88	-6.61	0.06	-0.06	0	0	0	0	0.05	0
Y14	2.6	-38.01	0.06	-0.06	0	0	0	0	0.05	0

Table I–2: Member displacement

	Dx mm		Dy mm		Dz mm	
	Max	Min	Max	Min	Max	Min
B1	6.73	-3.81	1.34	-11.6	15.07	-4.56
B2	11.89	-0.2	2.21	-14.07	14.88	-4.26
B3	17.02	0.69	4.34	-11.61	15.09	-4.55
B11	14.35	-5.74	1.63	-11.42	28.31	-6.69
B12	21.94	-0.35	2.33	-13.85	28.33	-6.67
B13	29.38	1.26	3.13	-11.42	28.36	-6.64
C1	0.09	-0.25	5.67	-14.35	28.31	0
C2	0.62	-0.32	0.31	-21.93	28.33	-0.26
C3	0	-0.5	0	-29.38	28.37	-0.13
C4	0.21	-0.25	5.73	-14.31	19.35	-6.82
C5	0.9	-0.33	0.35	-21.89	19.33	-6.67
C6	0.42	-0.17	0	-29.35	19.3	-6.64
J1	13.57	0.14	0.93	-15.16	4.53	-18.06
J2	12.06	-0.26	-4.05	-20.28	4.53	-18.06
J3	10.54	-2.41	5.8	-13.41	4.53	-18.06
J11	26.13	0.27	0.21	-13.66	6.76	-30.88
J12	23.94	-0.4	-3.65	-19.39	6.79	-30.88
J13	21.62	-3.54	3.8	-12.79	6.81	-30.86
S1	15.09	0.3	4.68	-5.67	4.53	-18.06
S2	9.03	-4.56	2.31	-4.19	4.53	-18.06
S11	28.36	0.58	4.15	-4.36	6.74	-30.88
S12	19.35	-6.69	2.64	-3.21	6.82	-30.86
X1	0	-0.79	3.78	-7.12	14.36	0
X2	0	-1.42	0	-12.54	14.38	0
X3	0	-0.76	0	-17.79	14.37	0
X4	0	-0.8	6.8	-4.09	3.55	-9.74
X5	0	-1.56	11.98	-0.5	3.56	-9.73
X6	0	-0.99	17.47	-0.01	3.54	-9.74
X11	1.72	-1.7	5.41	-14.52	27.26	0.31
X12	2.01	-1.35	0.17	-22.17	27.29	0.29
X13	4.53	-0.73	-0.74	-29.34	27.3	0.3
X14	0.95	-2.54	14.17	-5.8	5.19	-20.43
X15	-0.28	-3.04	21.79	-0.6	5.19	-20.41
X16	-0.37	-5.49	28.98	0.59	5.15	-20.4
Y1	0.51	-0.08	0	-15.55	2.77	-8.18
Y2	0	-0.71	15.49	-0.15	10.42	-1.19
Y3	0.39	-0.2	4.68	-9.29	0	-13.32
Y4	0.11	-0.41	9.28	-4.71	15.55	0
Y11	4.64	-0.07	-0.32	-28.15	4.37	-16.18
Y12	-0.18	-4.84	28.09	0.11	20.08	-1.61
Y13	2.78	-1.06	6.63	-19.31	0.18	-23.71
Y14	1.44	-3.03	19.23	-6.51	27.51	0.72

Appendix J: Steel drawings for the prototype house

Figure J-1: Steel structure. Floor plan

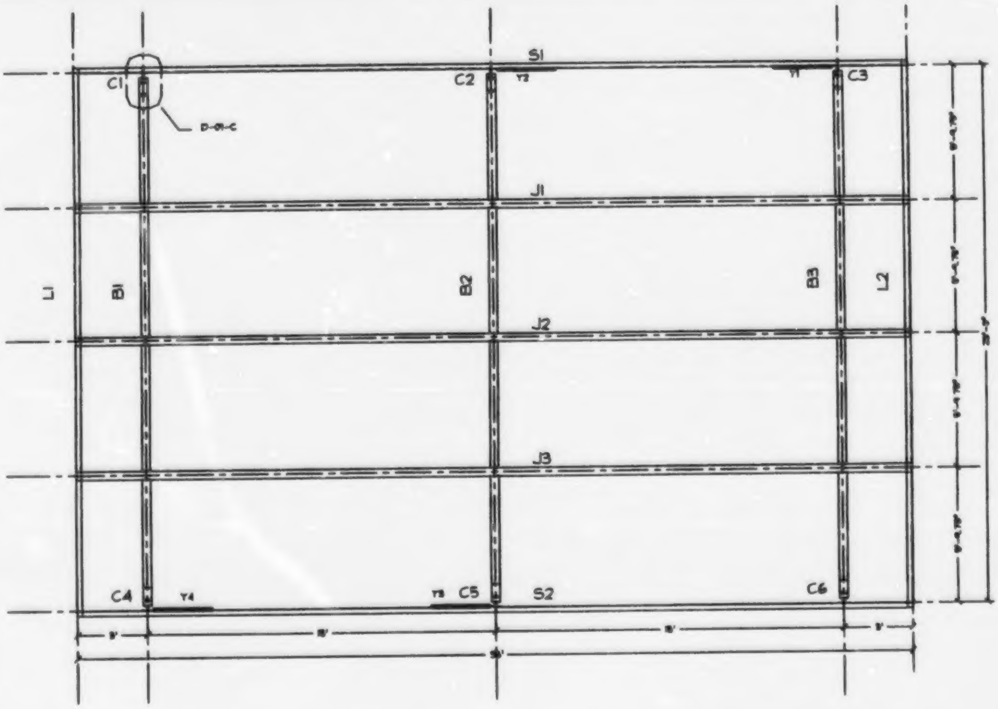
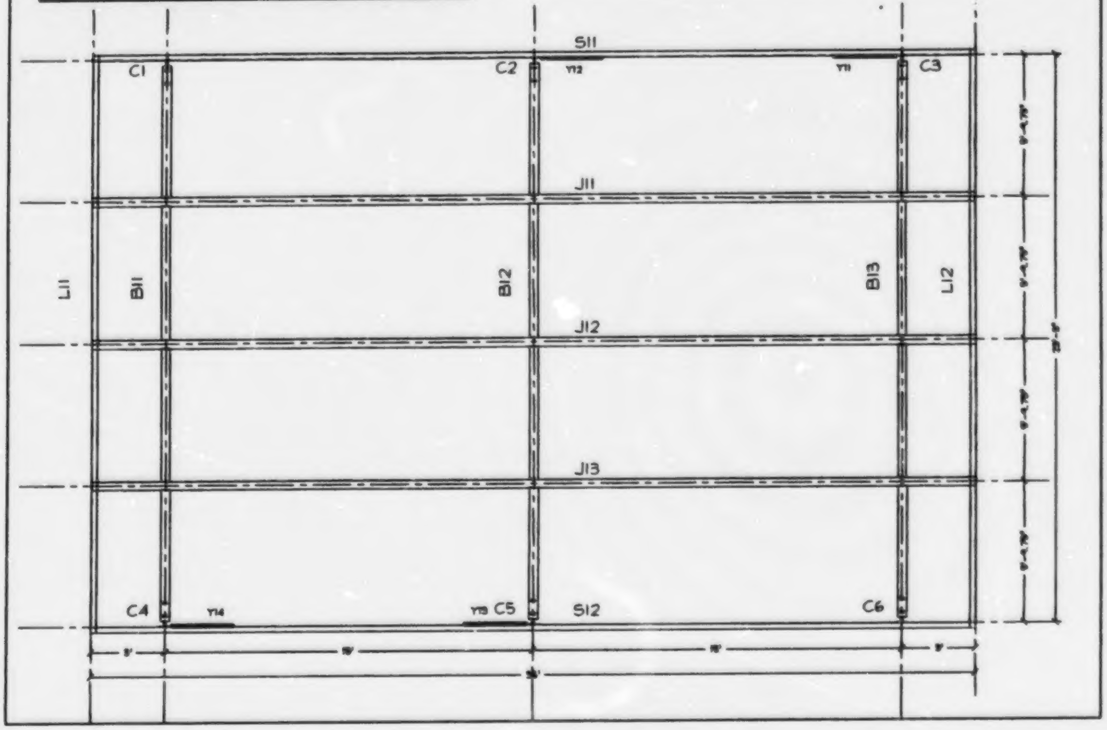


Figure J-2: Steel structure, roof plan



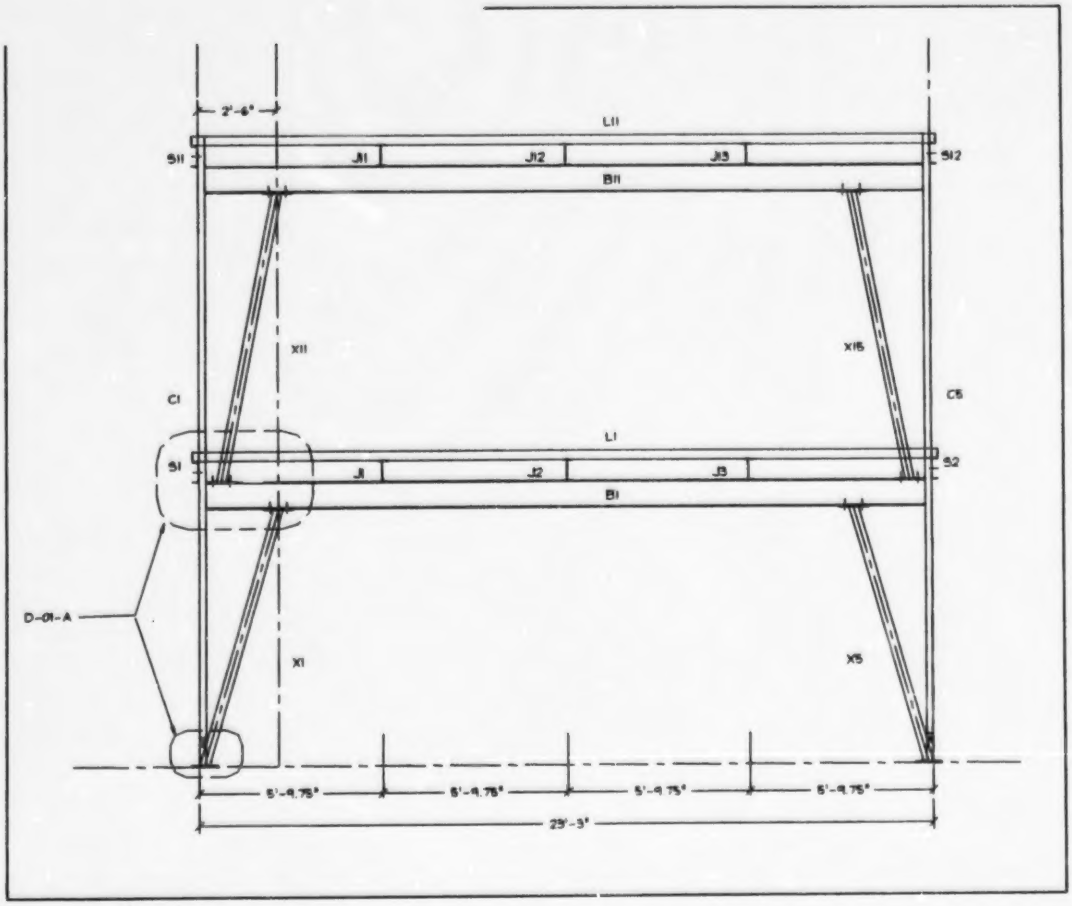

2'-6"
L11
S11
J11
J12
J13
S12
B11
X11
X15
C1
C5
L1
S1
J1
J2
J3
S2
B1
D-01-A
X1
X5
5'-9.75"
5'-9.75"
5'-9.75"
5'-9.75"
23'-3"

Figure J-4: Steel structure. Side elevation

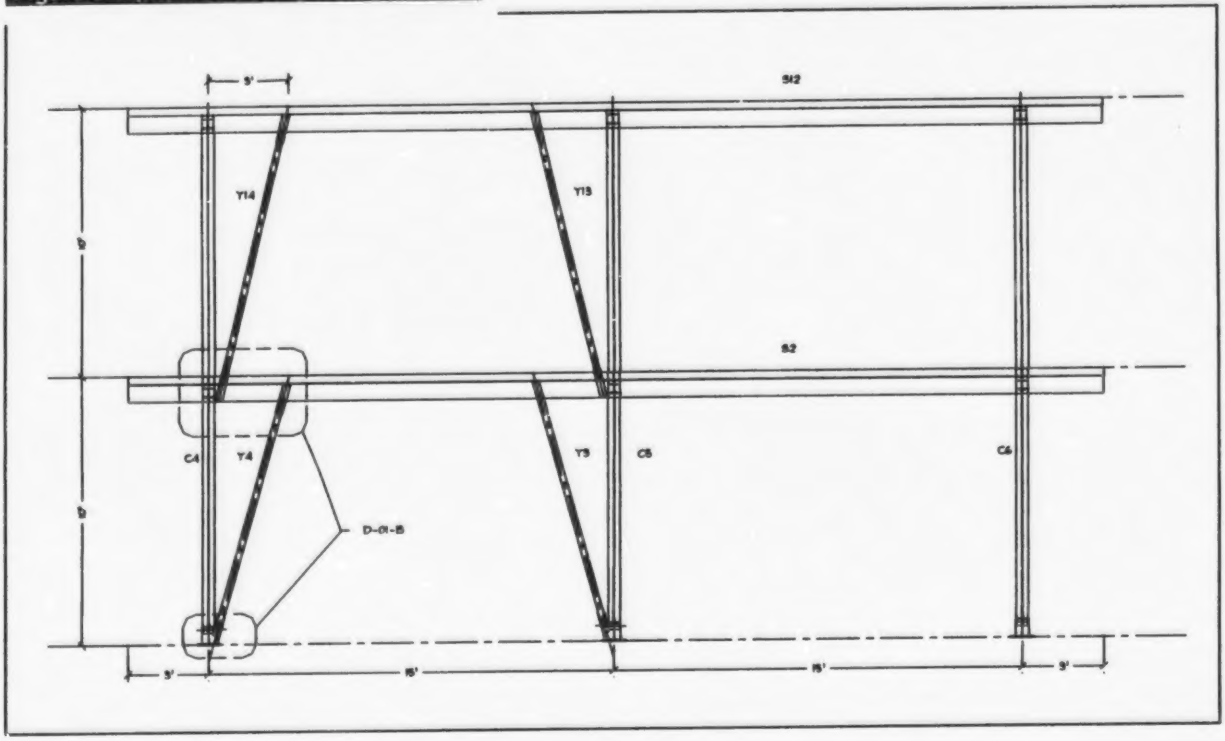


Figure J-5: Connection details – A: Front Bracing

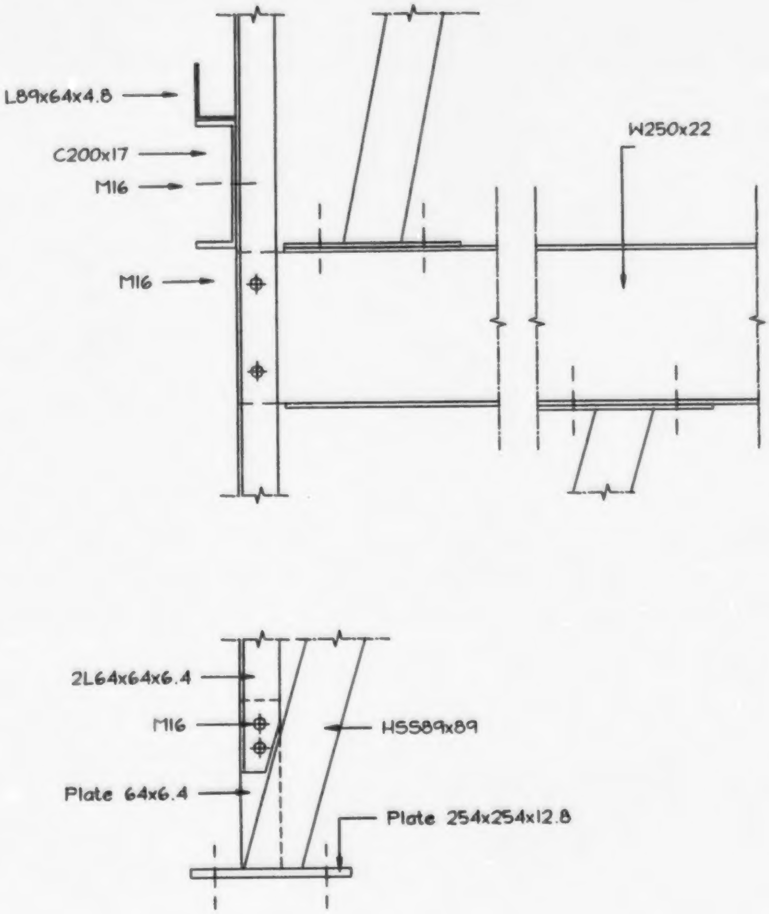


Figure J-6: Connection details – B: Side bracing

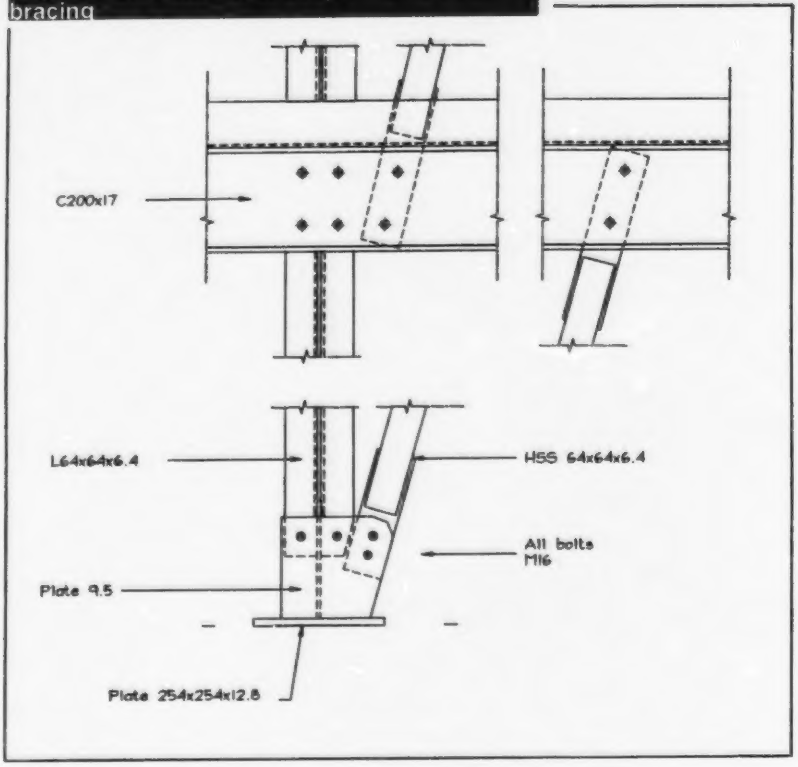
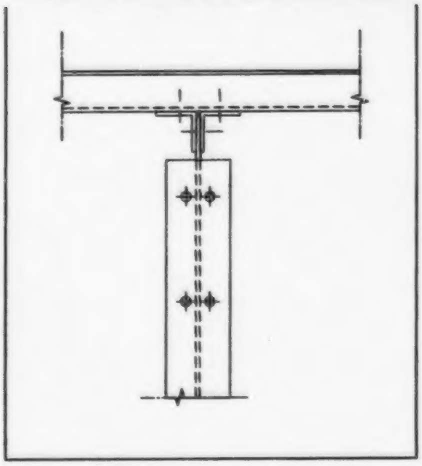


Figure J-7: C: Beam- Column Connection



Appendix K: Steel Elements

	Imperial			Metric		
Member	**Size Imp.**	**Length Ft**	**Weight Lbs**	**Size SI**	**Length m**	**Weight kg**
J1	W8x10	36.00	360.00	W200x15	10.973	164.6
J2	W8x10	36.00	360.00	W200x15	10.973	164.6
J3	W8x10	36.00	360.00	W200x15	10.973	164.6
J11	W8x10	36.00	360.00	W200x15	10.973	164.6
J12	W8x10	36.00	360.00	W200x15	10.973	164.6
J13	W8x10	36.00	360.00	W200x15	10.973	164.6
S1	C8x11.5	36.00	414.00	C200x17	10.973	186.5
S2	C8x11.5	36.00	414.00	C200x17	10.973	186.5
S11	C8x11.5	36.00	414.00	C200x17	10.973	186.5
S12	C8x11.5	36.00	414.00	C200x17	10.973	186.5
B1	W10x15	23.17	347.50	W250x22	7.061	155.3
B2	W10x22	23.17	509.67	W250x33	7.061	233.0
B3	W10x15	23.17	347.50	W250x22	7.061	155.3
B11	W10x15	23.17	347.50	W250x22	7.061	155.3
B12	W10x22	23.17	509.67	W250x33	7.061	233.0
B13	W10x15	23.17	347.50	W250x22	7.061	155.3
LS1	L3.5x2.5x3/16	36.00	133.20	L89x64x4.8	10.973	60.6
LS2	L3.5x2.5x3/16	36.00	133.20	L89x64x4.8	10.973	60.6
LS11	L3.5x2.5x3/16	36.00	133.20	L89x64x4.8	10.973	60.6
LS12	L3.5x2.5x3/16	36.00	133.20	L89x64x4.8	10.973	60.6
L1	L3.5x2.5x3/16	23.17	85.72	L89x64x4.8	7.061	39.0
L2	L3.5x2.5x3/16	23.17	85.72	L89x64x4.8	7.061	39.0
L11	L3.5x2.5x3/16	23.17	85.72	L89x64x4.8	7.061	39.0
L12	L3.5x2.5x3/16	23.17	85.72	L89x64x4.8	7.061	39.0
C1	2xL2.5x2.5x.25	20.00	164.00	2xL64x64x6.4	6.096	73.3
C2	2xL2.5x2.5x.25	20.00	164.00	2xL64x64x6.4	6.096	73.3
C3	2xL2.5x2.5x.25	20.00	164.00	2xL64x64x6.4	6.096	73.3
C4	2xL2.5x2.5x.25	20.00	164.00	2xL64x64x6.4	6.096	73.3
C5	2xL2.5x2.5x.25	20.00	164.00	2xL64x64x6.4	6.096	73.3
C6	2xL2.5x2.5x.25	20.00	164.00	2xL64x64x6.4	6.096	73.3
Y1	HSS2.5x2.5x.25	11.66	82.92	HSS64x64x6.4	3.555	37.7
Y2	HSS2.5x2.5x.25	11.66	82.92	HSS64x64x6.4	3.555	37.7
Y3	HSS2.5x2.5x.25	11.66	82.92	HSS64x64x6.4	3.555	37.7
Y4	HSS2.5x2.5x.25	11.66	82.92	HSS64x64x6.4	3.555	37.7
Y11	HSS2.5x2.5x.25	11.66	82.92	HSS64x64x6.4	3.555	37.7
Y12	HSS2.5x2.5x.25	11.66	82.92	HSS64x64x6.4	3.555	37.7
Y13	HSS2.5x2.5x.25	11.66	82.92	HSS64x64x6.4	3.555	37.7
Y14	HSS2.5x2.5x.25	11.66	82.92	HSS64x64x6.4	3.555	37.7
X1	HSS3x3x.25	11.66	102.62	HSS76x76x6.4	3.555	46.6
X2	HSS3.5x3.5x.25	11.66	122.45	HSS89x89x6.4	3.555	55.5
X3	HSS3x3x.25	11.66	102.62	HSS76x76x6.4	3.555	46.6
X4	HSS3x3x.25	11.66	102.62	HSS76x76x6.4	3.555	46.6
X5	HSS3.5x3.5x.25	11.66	122.45	HSS89x89x6.4	3.555	55.5
X6	HSS3x3x.25	11.66	102.62	HSS76x76x6.4	3.555	46.6
X11	HSS3x3x.25	11.66	102.62	HSS76x76x6.4	3.555	46.6
X12	HSS3.5x3.5x.25	11.66	122.45	HSS89x89x6.4	3.555	55.5
X13	HSS3x3x.25	11.66	102.62	HSS76x76x6.4	3.555	46.6
X14	HSS3x3x.25	11.66	102.62	HSS76x76x6.4	3.555	46.6
X15	HSS3.5x3.5x.25	11.66	122.45	HSS89x89x6.4	3.555	55.5
X16	HSS3x3x.25	11.66	102.62	HSS76x76x6.4	3.555	46.6
Total	**50Elements**		**10,059.13**			**4,554.7**

Appendix L: Steel Deck Loads

Table L1: Composite decks

Composite solution			
Thickness concrete	100.00	mm	Include deck flutes
Load concrete	1.86	kPa	(1)
Floor finish (tiles, etc,...)	0.25	kPa	
Live Load	1.9	kPa	
Construction Crew Load	1.00	kPa	During pouring of concrete
Deck	P-3615		
Steel Deck Thickness	0.91	mm	
Span (Quadruple span)	1,905	mm	
Max span w/o shoring	2,070	mm	During construction
Check shoring	***2070>1905***		***OK***
Composite Moment of Inertia	5.251	mm4	I_{comp}
Module Elasticity steel	200,000	MPa	E_{steel}
Max Factored load	5.49	kPa	1.25 Dl + 1.5 LL
Max load on deck	20	kPa	(1)
Check Factored Load	***20.00>5.49***		***OK***
Service Load	1.90	kPa	
Deflection	0.31	mm	(2)
1/360 deflection	5.29	mm	
Check deflection	***5.29>1.90***		***OK***

(1) According to Canam load table Manual for composite Steel decks

(2) Calculated by Formula : $(5 \times W_L \times l^4) / (384 \times E_{steel} \times I_{comp})$

Table L-2: Deck with drywall

Drywall thickness	16	mm	5/8 "
Number drywall sheets	3		
Dead load Drywall kg/m2	40.80	kPa	
Dead load	0.40	kPa	
Floor finish (tiles, etc,...)	0.25	kPa	
Live Load	1.9	kPa	
Deck	P-3615		
Steel Deck Thickness	0.76	mm	
Span (Quadruple span)	1828.8	mm	
Max Factored load	3.67	kPa	1.25 Dl + 1.5 LL
max load on deck	6.32	kPa	(3)
Check Factored load	***6.32>3.67***		***OK***
Max service Load	2.55	kPa	
Load at 1/360 deflection	2.97	kPa	(3)
Check deflection	***2.97>2.55***		***OK***

(3) According to Canam load table Manual for Steel decks

Appendix M – Sustainability limits indicators

Renewable resources

Human biomass appropriation	Human economy directly of indirectly uses about 40 percent of the net primary product of land-based photosynthesis and ¼ of the total, including oceans. Cutting tree reduces biomass, deforestation reduces the environment sink effect, and destroys habitat.
Protein demand	Protein demands are projected to double in the century ahead. The oceanic fish catch has plateaued to 90 million tonnes per year since 1990 and will not meet those demands. *"Bad news for oceans is bad news for the economy and ultimately for humanity too,"* People obtains an average of 16 percent of their animal protein from fish. Many fisheries are collapsing or have already collapsed: e.g. Canadian cod off the coast of Newfoundland, pacific salmon in the Northwest, sturgeon in the Caspian sea.
Deforestation	Tropical forests have already been 55 percent destroyed. The current rate of destruction is 168,000 km2 per year
Diminishing bio-diversity	Tropical forests, which are been destroyed, are the world's richest species habitat. Conservative estimates indicate that 5,000 species are extinct each year. Less conservative estimates mention 100,000. This extinction rate is 10,000 x faster than pre-human extinction rate. Of the 242,000 plant species surveyed by the World Conservation Union in 1997, some 33,000 — or 14 percent — are threatened with extinction, mainly as a result of massive land- clearing.
Falling water tables	Water use tripled since 1950. Water table are falling on every continent. Texas has lost 11% of its irrigation. Water table in Punjab, the breadbasket of India is falling at a rate of 60 cm per year, in central and northern China, it is falling by more than one meter per year.

Land use

Land degradation.	35% of earth's land is already degraded. The soil erosion rate is between 10 to 100 tons per hectare. 6 millions hectares are abandoned every year. Clearing of tropical forests has contributed to unprecedented fires across large areas of Southeast Asia, the Amazon, and Central America.

Sink

Green house gas emissions	The main green house gases are carbon dioxide (CO2), methane (NH4), and nitrous oxide (N20). CO2 emission are 20 billions tonnes per year.. The U.S. and Canada, with only 4% of the world's population are responsible for 24% of the world's annual greenhouse gas emissions over the last two decades. Global carbon dioxide concentrations have increased by 30% to 385 ppmv in 1995 from the pre-industrial level of about 280 ppmv. GHG emissions are growing at a rate of 1.5 ppmv per year (0.4% per year). Today's world methane concentrations are about 1720 ppbv, some 2.5 times greater than the pre-industrial concentration of around 700 ppbv, and are currently growing by 8 ppbv per year (0.46% per year). In 1995 global nitrous oxide concentrations in the atmosphere were estimated to be about 312 ppbv, about 15% above the pre-industrial level, and are growing by 0.5 ppbv per year (0.16% per year).
Climate Change:	1997 was the hottest year this century, having been 0.43°C warmer than the mean temperature for 1960-1990. Higher temperatures are projected to threaten food supplies in the next century, while more severe storms cause economic damage, and rising seas inundate coastal cities. The increase of CO2 in the atmosphere shows that ecosystem carbon-absorption sinks have been exceeded
Rupture of the Ozone shield.	The main hole in the ozone layer is the size of North America by 20 km high

Population

Population size	Today's world population is 5.9 billion and will reach 6 billion in the year 2000. Population in 2050 is expected to be in the range of 7.3 to 10.7 billion
Population explosion	The population doubled in the last 40 years Population increases at a rate of 100 millions per year or 1.33 % per year. In 1804, the world population attained one billion. It took 123 years to reach 2 billion people in 1927, 33 years to attain 3 billion in 1960, 14 years to reach 4 billion in 1974, 13 years to attain 5 billion in 1987 and 12 years to reach 6 billion in 1999
Third World.	Population in third world country is 77 % of world's today. Third world represents 90 percent of world annual population growth.

Social

Inequity	The top 20% of the population earns 60 times the income of the bottom 20%. 80% of the population of industrialized countries lives in cities The wealthiest 25% of the human population consume 80% of the world economy
Poverty	¼ of population lives in poverty In Africa, where populations have doubled in the last three decades, economic growth is failing to keep up with human needs

Economy

Growth	The global output of goods and services grew from just under $5 trillion in 1950 to more than $29 trillion in 1997, a sixfold expansion. The economy grew by $5 trillion from 1990 to 1997 matching the growth from the beginning of civilization to 1950. From 1950 to 1997, the use of lumber tripled, the paper consumption tripled, the fish catch increased fivefold, grain consumption nearly tripled, fossil fuel burning nearly quadrupled, and air and water pollutants
Losses	1998 has set a record for economic losses from weather-related disasters. Storms, floods, droughts, and fires caused at least $89 billion in economic losses worldwide. It represents a 48 percent increase over the previous record of $60 billion in 1996-and far exceeds the $55 billion in losses for the entire decade of the 1980s. During the first three-quarters of 1998, the U.S. insurance industry alone had weather-related claims of more than $8 billion-three times the claims in 1997.

Appendix N: Advantages of Steel Framing

The following is an excerpt of the advantages of steel framing according to the AISI. The technology implied is steel stud framing, which is not the technique put forward in this report. Nevertheless, the inherent benefits of steel in terms of strength, durability, recyclability, flexibility, and economy remain the same, regardless of the technology.

Steel has long been the building material of choice for commercial construction for reasons of strength, durability and stability. Recyclability and recycled content are another factor that has moved to the forefront of benefits. Steel construction material is every bit as recyclable as the steel can found in kitchens across America. In fact, the steel used in construction projects today may have been made from steel cans and other steel products recycled yesterday. This is possible because steel scrap is an essential ingredient in making new steel. As steel is recycled, it maintains its strength and integrity so it can be made into one quality product after another.

Builders across the United States and Canada are constructing all types of steel-framed homes: multi-family housing developments, retirement homes and single-family residences. An estimated 125,000 homes were built in 1995 with steel framing.

There are many benefits of using steel framing: it's light weight, cost effective, noncombustible, performs well in high wind and seismic areas and resists corrosion. Of course, once the home has lived out its useful life, the steel framing can be recycled.

By the year 2000, an estimated 25 percent of all new homes built in the United States will be framed in recycled, recyclable steel.

For reasons of strength, durability, versatility and economy, steel is a universal building material. Today, an increasing number of builders have discovered lightweight steel framing to construct homes, and are doing so with great success. Steel's sudden growth in residential popularity has been fueled by both economic and environmental considerations in the building industry. Wood has been the material builders traditionally used to construct residential homes in North America. But as a result of more than 90 percent of North America's old-growth forests already being harvested, wood's cost has increased while its overall quality and availability have dwindled.

Wood remains an important material for contractors, but steel offers many construction advantages, as well as environmental benefits.

Steel is lightweight, cost effective, easy to use, recycled and recyclable.

Steel framing is easy to handle on-site. It is light in weight because steel has the highest strength-to-weight ratio of any construction material, resulting in the use of less framing material compared to wood for an equal size structure.

Steel framing is cost effective. It can be purchased to specific lengths, minimizing job site scrap. Steel does not twist, warp or split, so there is no need to sort out poor quality product, which saves time and money. An average 2,000 square foot steel framed house can generate as little as a cubic yard of recyclable scrap. Builders reduce their disposal costs, and divert material from local landfills.

More builders are taking advantage of panelizing: either building or purchasing pre-assembled wall, floor and truss components. Steel's consistent quality and dimensional stability enhance efficiency in-plant or at the job site. Panelizing helps speed the framing process for the builder.

Steel is noncombustible, performs well in high wind and seismic areas, and resists corrosion. It doesn't shrink or swell with time or humidity changes, so steel framing contributes to better drywall and exterior appearance, as well as the fit of doors and windows.

All steel products, including steel framing, contain recycled steel. Steel framing contains at least 28 percent recycled steel and is completely recyclable. Using recycled steel takes the pressure off renewable resources: a typical 2000-square-foot home requires about 40 to 50 trees, about an acre's worth. With steel, only the equivalent of about six scrapped automobiles are needed.

In contrast to many other building materials, steel is routinely collected in aggregate quantities from construction and demolition sites and recycled into new steel products.

At the end of a steel-framed home's useful life, the steel components would also be recyclable. Framing with steel as a material consumes only 6.25 percent of the total life-cycle energy used by a home; the balance is consumed by heating and cooling, food refrigeration and lighting. Thermal barrier insulating materials provide exceptional heat and cooling loss protection to steel-built homes. Additionally, steel framing results in less air loss around windows and doors as well as foundation and roofing connections.